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UNITED STATES GEOLOGICAL SURVEY
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Water-Supply Paper 375

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

1915

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The valley was the stronghold of the Americans during the conquest in 1845, and many of the settlers became rich in the mines in the years following the discovery of gold in 1848. The commercial production of wheat in this area was begun by Gen. John Sutter in 1843,[1] and until very recently the growing of wheat and barley by dry-farming methods has been the principal agricultural industry.

The use of water for irrigation has developed slowly and has encountered a curious apathy, in contrast to the enthusiasm for reclamation by drainage. Because of a mild climate, a concentrated winter rainfall, and a shallow water table, many field crops and deep-rooted plants thrive without irrigation. Water is not a necessity; it only makes possible larger yields, the cultivation of crops with a higher return to the acre, and the cultivation of certain lands otherwise chiefly valuable for grazing. Such advantages have had little weight with owners of large holdings to whom the original cost of the land was small. However, the crowding in of home seekers from the East, the diminishing profits of grain farming, and the increase in land values have combined to bring about the subdivision and sale of many large parcels of land. To the purchasers of such tracts the advantages of irrigation appeal more strongly.

The price of land is based on its anticipated value under irrigation and not on its value for dry farming. When subdivided, it is sold for two to three times its value for grain raising, and for many tracts the purchaser must provide the means of irrigation. The colonizing of subdivided lands has become a business and is in the main conducted by reputable firms. A large block of land is purchased and surveyed into small tracts with provision for roads and perhaps for a town site. Irrigation works may be provided or a demonstration well and pumping plant installed with the intention that the settlers should install private plants, using wells for obtaining water. Purchasers are attracted by agents and advertising. Charges of fraud have been made and doubtless in some cases are justified, but wide publicity and cooperation among real estate men are eliminating false and exaggerated statements. Intending settlers should exercise caution, view the property, compare it with similar offers, and be sure that they are getting good land well situated for a fair price. The value of farm land rests primarily on the quality of the soil and the value of the crops which it will produce, but the price of similar land varies with proximity to market, towns, and schools, with danger of floods and assessments for reclamation, with the kind of irrigation feasible, and with many other local factors. The formation of an intelligent judgment will be assisted by a study of reports of the United States Bureau of Soils, covering large parts of the valley, which are given in the following list:

[1] Bancroft, H. H., History of California, vol. 5, p. 228, and note, p. 187.

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ticularly to the commercial production of grapes, figs, olives, citrus and deciduous fruits, and nuts.

The character of the climate is accurately reflected in the life of the people. With the beginning of the rains in the fall the grass springs up and cattle and sheep are brought down from the mountains, where they have passed the summer. The overflowed tule lands in the center of the valley are grazed only in the long, dry summer, and with the coming of the rains the cattle are moved to the higher plains. The grain farmer sows his wheat and barley in the fall and harvests them in the spring; this is called winter sowing. Or he may plow his land after the rains in the spring and let the plowed land lie fallow through the summer, to be planted before the rains in the fall; this is known as summer fallowing. Because the ground is too dry and hard to plow after the grain ripens, land that bears a crop can not be summer fallowed the same year, so that summer-fallow land has a crop only every other year. The concentration of the rainfall, with a shallow water table, enables all deep-rooted plants to survive the summer, while the mild temperatures are favorable for delicate plants. On these conditions rests the orchard industry of the valley. All the deciduous fruits bear heavy crops and are rarely damaged by frost. The more delicate fruits and nuts—apricots, almonds, walnuts, olives, lemons, and oranges—grow well and are a commercial success in favored localities. The extensive grape industry is also dependent on the climate; the less hardy varieties of the vine may be grown, and the long dry season is favorable to the concentration of sugar in the grapes and to the drying of the grapes to make raisins.

Many districts in the valley are famous for certain special crops. This does not mean that these crops can not be grown with profit elsewhere, but only that they have been found to be especially well adapted to the particular soil, climate, and water of those districts. There is a tendency to magnify the differences between localities through prejudice and self-interest, but real differences exist that are sufficient to affect the quality of many crops. Without taking any natural advantage into consideration, it is obvious that, in growing an export crop, association with other growers of the same crop is beneficial, especially to the inexperienced, through standardization of methods of culture and marketing.

WATER-BEARING FORMATIONS.

PRE-TERTIARY ROCKS.

The Sacramento Valley is a basin whose sides and bottom are probably formed of the same granitic, schistose, and slaty rocks, of pre-Cretaceous age, that compose the greater part of the Sierra Nevada

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and the core of the Coast Ranges. In this basin lie sandstones and shales of Cretaceous age, which are thin on the east side but thicker on the west.[1] These formations carry little water and may be considered as an impervious floor on which the Tertiary and Quaternary water-bearing formations have been deposited.

The geologic history of the valley is long and complex, as is shown by the evidence derived from the rocks of bordering regions. An arm of the sea existed approximately in the position of the valley intermittently for a long time, but the depression that began in the Tertiary period, modified by Quaternary movements, gave to the valley its present shape.

TERTIARY SEDIMENTS.

During the Tertiary period two formations were deposited in this basin—the Tejon, which belongs to the Eocene series, and the Ione, which was originally described as Miocene but is now held by Dickerson[2] to be Eocene. Neither of these is important as a water-bearing formation.

The Ione has not been recognized in wells of the valley, but deep wells near Lincoln obtain salty water from fine sand below a thick blue clay, or shale, which is either the Ione or the underlying Cretaceous.

TERTIARY LAVAS.

In Tertiary time lavas, breccias, and tuffs were extruded from volcanoes in the Sierra Nevada and extended down the slopes of the mountains and into the valley.

ANDESITE BRECCIAS AND BASALT.

The lava flows which cap the gold-bearing gravels in the ancient stream channels of the Sierra and which diverted the rivers into their present channels covered the Ione formation on the edges of the valley and now extend as a bed of lava grading into tuff beneath the more recent sediments in the valley, as is shown by the deeper wells of the east side. In some wells good water is obtained in sands and gravels that apparently occur at this horizon.

Basalt of similar history and origin caps the Ione formation in South Table Mountain, near Oroville, and in a group of hills farther north. The basalt is not known as a water bearer in the valley, but rain water which enters its jointed and porous outcrops seeps out at its contact with the Ione to form several perennial springs in the mountain and the basalt-capped hills near by.

---

[1] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 415, 1894. Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Sacramento folio (No. 5), 1894.

[2] Dickerson, R. E., The Ione formation of the Sierra Nevada foothills, a local facies of the upper Tejon-Eocene: Science, new ser., vol. 40, pp. 67-70, 1914.

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TUSCAN TUFF.

From Durham northward to Red Bluff and beyond the Sierra foothills are formed by beds of andesite lava, breccias, and volcanic ash aggregating 1,000 to 1,500 feet in thickness. These beds, which are known as the Tuscan tuff, consist of materials that were extruded from volcanoes in the vicinity of Lassen Peak.[1]

The formation is considered by Diller to be of Pliocene age, but small eruptions of similar material have continued through Quaternary time to the present day. That a long time was needed for the accumulation of these beds is shown by the presence of interbedded gravels whose smooth, waterworn pebbles of andesite and basalt were deposited by large graded streams that flowed over the volcanic plain and eroded its surface between successive volcanic eruptions. The main mass of the volcanic material to which the name Tuscan is given, was uplifted by a monoclinal fold (Chico monocline) extending along the border of the Sacramento Valley from Chico northwestward to Iron Canyon. This movement, which involves also the older alluvium, lifted the Tuscan tuff from 500 to 900 feet above the valley. In the plain thus formed a number of deep and desolate gorges have been cut by perennial streams, of which Antelope, Mill, Deer, Chico, and Butte creeks are the largest.

From the foothills of the Sierra the Tuscan tuff extends beneath the alluvium of the valley with diminished thickness and increasing fineness of grain. It is exposed about 12 miles west of Sacramento River along Thomas, Elder, and Redbank creeks as a pinkish tuff about 50 feet thick overlying the Ione formation. Little is known of the water-bearing properties of the Tuscan formation on the west side, but on the east side near Chico there are seven wells which penetrate the formation. The lowest yield is 600 gallons a minute. In the center of the valley shallow wells are likely to furnish sufficient water, but on the higher plains from Durham northward to Red Bluff, where the alluvium is thin and cemented, wells should be sunk to the Tuscan tuff if large supplies are needed. The dip of the formation is 10°–15° W. at the edge of the valley but flattens to horizontal in the center. Thus the depth to the formation within 2 or 3 miles from the outcrop east of Chico increases to 500 feet, but farther out in the valley it seems to lie at no greater depth. These relations are brought out in figure 1.

The depth of the formation beneath the valley has been estimated by interpretation of the well logs. The wells of the Chico Water Co. and the Morehead wells (see fig. 1) are certainly in the lavas at the depths indicated, but the Parrott well has a log which is not quite so

[1] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 412, 1894.

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easily interpreted. The "lava ash" reported at 377 feet and again at 399 feet may be only a fine silt and not a tuff bed of the Tuscan formation.

The inclined position of the Tuscan tuff is favorable for artesian water, but the absence of an impervious cover prevents the accumulation of the necessary head. Certain beds within the formation seem to be dry, and in many of the wells water stands slightly below the level of water in near-by shallow wells. In the wells of Stanford University east of Durham, however, the water stands 3.5 feet above the water table in the alluvium.

Drilling in the Tuscan tuff is difficult because the rock is hard and deep wells are necessary. The expense of drilling will be justified only where large supplies are needed or for stock and domestic water

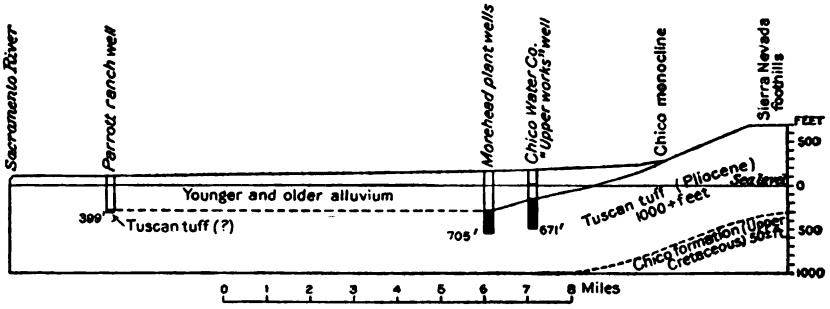

FIGURE 1.—Section through Chico, Cal., showing probable position of Tuscan tuff.

on the stony plains east of Vina, where shallow wells go dry in summer.

TUFF BEDS OF THE WEST SIDE.

Evidence of volcanic activity in the Coast Range is abundant. Ash beds and tuffs below the older alluvium and fine tuffs in the older alluvium of the west side indicate that in part at least this volcanism in the Coast Range was coincident with the Pliocene and Pleistocene eruptions of the Sierra Nevada.

OLDER ALLUVIUM.

The great volcanic eruptions of the Pliocene epoch were followed by uplift and erosion around the borders of the Sacramento Valley, but probably by continued deposition in the center. Deposition over the whole valley area then began and continued into Pleistocene time. The deposits thus laid down are known only where they have been exposed by later uplift on the borders of the valley, and when encountered in wells they can rarely be distinguished from the overlying younger alluvium. At the edge of the valley they rest on the andesite lava, the Tuscan tuff, and the Ione formation, in some places

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in apparent conformity, but in many places with evidences of extensive stream cutting before their deposition. In some localities the Tertiary beds have been removed and the alluvium lies directly on the granites and schists.

The older alluvium is of Pleistocene and possibly late Pliocene age and is differentiated from the younger alluvium only by the fact that it is now uplifted and dissected. It is composed of clay, sand, and gravel, and varies much in appearance and composition. It is characteristically red and is always redder than the neighboring younger alluvium, but the shade changes from place to place and samples from different areas have no superficial resemblance. This is due to the fact that the alluvium was deposited by streams varying in volume and permanence and draining areas of different types of rock. Only the deposits of tributary streams are exposed; the contemporary deposits of Sacramento River are now deeply buried. Four large divisions of the younger alluvium can be made and mapped—the southeastern, the northeastern, the southwestern, and the northwestern.

SOUTHEASTERN DIVISION.

The southeastern division of the older alluvium extends from Oroville southward to Lodi and comprises the deposits of Feather, Yuba, Bear, American, Cosumnes, and Mokelumne rivers. In Pleistocene time these strong streams trenched great canyons in the Sierra Nevada and discharged the eroded materials into the valley. The Sierra throughout this region is composed largely of granite and the alluvium is everywhere arkosic; that is, it contains undecomposed particles of feldspar and mica, with quartz, the constituent materials of this rock. The clay is red or brownish red, is tough and tenacious, and contains particles of iron-stained feldspar and muscovite mica. The sands are quartzose and carry a little feldspar and much mica, both muscovite and biotite. The gravels are usually well-rounded pebbles of the harder rocks. Quartz and quartzite pebbles predominate, but pebbles of granite, diabase, andesite, and schist also occur. In size they range from cobblestones near the mountains to pebbles an inch or less in diameter near the center of the valley. The gravels are in most places cemented with calcium carbonate, and "hardpan" is common throughout the formation. Hardpan composed of clay or sand cemented with lime and hydrous silicates of iron is commonly found near the surface. It is covered with a few inches to several feet of red soil, which has a superficial coat of pebbles due apparently to concentration by rain wash. Such soil and hardpan are characteristic of the higher plains. Irrigation and special treatment of the soil are necessary for full agricultural development of the rolling plains and hills of this formation.

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Wells in this formation should be drilled, as it is too hard for successful auger work except in certain favored places. Water is usually obtained from fine sand, as the gravels of the formation are commonly so cemented as to furnish but little water. Because the clays stand without casing the sand is usually pumped out and water is drawn from the cavities thus formed. Wells so constructed have a large seepage area and many of them, particularly in the lower part of the plains, are very successful.

NORTHEASTERN DIVISION.

The older alluvium of the northeastern division extends in irregular patches from Oroville to Chico and is more conspicuous from Chico along the east-side plains to Red Bluff. It is of the same age and was formed by the same processes as the older alluvium farther south, but as the comparatively short streams which furnished the sediments had their courses over the great blanket of Tertiary lavas that here mantle the Sierra the deposits are composed almost wholly of volcanic materials. The older alluvium of this part of the valley is thin, being nowhere over 60 feet thick where uplifted along the Chico monocline, and is composed chiefly of rather large, waterworn gravels, cemented by lime, with smaller amounts of brown clay and sand. The color of the formation as a whole is a deep brown, of slightly redder hue than the brown of recent deposits. Only small patches occur between Oroville and Chico, but north of Chico the older alluvium is the predominant surface formation on the east side of the valley. The surface is a treeless plain, covered with large and small stones, the finer material having been washed away by the rain. A thick grass springs up between the stones after the fall rains, and at such times the plains are used for grazing. Dug wells have been the common type in this area and have not been very successful. Drilled wells are more likely to develop water, but large supplies can not be expected from the older alluvium in this division.

NORTHWESTERN DIVISION.

The northwestern division of the older alluvium extends from Stony Creek to Red Bluff. It forms a prominent bluff that overlooks the river and, with the prevailing red color, gives the name to Red Bluff and to several other local features. The clays, sands, and gravels of the formation were deposited by the Sacramento and its western tributaries. The gravels are in places 2 to 3 inches in diameter and are composed of igneous and metamorphic rocks from the Klamath Mountains. The formation is thin where it rests on the Tuscan tuff about 12 miles west of the river and is over 400 feet thick near the river. The upper part laps over the east-side alluvium in the vicinity

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Another fault, en échelon with this one, starts at Esparto and, skirting the mountains, brings up the alluvium along the foothills to a point opposite Allendale, where the fault disappears. Farther south, around Elmira, the older alluvium comes close to the surface of the plains, which are only veneered with modern wash. It reappears in the Montezuma Hills, a well-dissected plateau of alluvium about 200 feet high on the west with a gentle slope to the northeast. These hills form the terminus of the plains and confine the waters of the Sacramento and San Joaquin in a narrow throat against the Mount Diablo Range, with Suisun Bay on the west and the island country on the east.

YOUNGER ALLUVIUM.

GENERAL CHARACTER AND DISTRIBUTION.

The deposition of the older alluvium was followed by uplift in both the Sierra Nevada and the Coast Range, which is regarded as part of the Pleistocene uplift of these ranges. The edges of the valley were bent up and the center gently bowed down. From Lodi to Oroville along the east side there was a gentle raising and tilting of the valley edge. The alluvium was lifted from 100 to 400 feet above the stream grades, causing each stream to cut a canyon of alluvium as it emerged into the valley. There were two pauses in the cutting of these canyons, marked by well-defined terraces. From Chico north to Red Bluff the movement was a sharp monoclinal flexure, which formed the Chico monocline and raised the Tuscan tuff about 900 feet. The alluvium, except where bent up in the fold, was raised between 50 and 150 feet above stream grade. The shallow valleys which traverse the plain of older alluvium show one terrace very prominently and in most places two.

On the west side from Red Bluff to Stony Creek each tributary valley which crosses the broad plains of the older alluvium shows terraces, as a rule the typical two. A general uplift took place at the north end of the valley, and there was less central deepening, well records indicating that the younger alluvium is less than 150 feet deep in the river bottoms. From Stony Creek south to Williams there was a sharp downward flexing, and the modern alluvium lies close to the mountains. From Williams southeast to Cache Creek the Hungry Hollow fault raises the older alluvium in the little plateau whose southern part forms the Hungry Hollow Hills. The streams that cross the plateau at right angles to the fault line have two well-developed terraces. Similarly Cache Creek shows two terraces where it crosses the fault and a similar set where it emerges from the mountains at Esparto.

With the uplift just described Sacramento River and its tributaries began the deposition of the younger alluvium, the material being eroded from the older alluvium or brought down from the mountains.

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The younger alluvium covers the central area of the valley and lies in narrow strips along the tributaries of the Sacramento. It varies in character, like older alluvium, but the deposits of the main river which it includes are exposed in addition to those of the side streams. The formation is probably nowhere in the valley more than 300 or 400 feet thick. Every high water adds to it, and this fact is so well understood that some farmers deliberately turn flood water on their land for the benefit derived from the "sediment."

The younger alluvium is the most productive water bearer of the valley formations. It is uncemented over most of the area and consists largely of sands and gravels. Many house wells draw water from the clays, but except under unusual conditions large supplies are derived only from the sand or gravel. Successful development consists in the search for sufficient sand and gravel and in the use of adequate well methods.

These beds were deposited by the present streams, and the coarsest and cleanest gravels were formed by the larger streams. But as these streams in building up the valley deposits have shifted their courses many times, their gravels are found over a wide area. The gravels are not continuous beds but irregular lenses and strings of material separated by sand and clay. Consequently the logs of adjacent wells are often very unlike. Where a stream is confined in a valley of older alluvium it is comparatively easy to sink a line of wells across the valley and determine the place where the maximum amount of gravel has been deposited. Where a stream debouches from the mountains directly upon the plain its deposits occupy a triangular area with the apex near the mountains. The gravels, representing old stream courses, extend in irregular wavy lines from the apex to the base. The largest amount of gravel is then at the mouth of the canyon, and the smallest near the mountains in the interstream areas.

Along the larger rivers wells draw from either sand or gravel and the gravels encountered are of the same size as those in the river bed at that place. Thus the Sacramento has gravels 3 to 6 inches in diameter near Red Bluff, 2 to 3 inches at Hamilton, 1 to 2 inches at Butte City, and about 1 inch at Colusa. From Colusa southward gravels are rare, but the sands are in many places coarse and gravelly, and even as far south as Rio Vista pebbles half an inch in diameter are found in the sands. Feather River carries gravels 6 to 8 inches in diameter at Oroville, but at Marysville most of its load is sand.

LOCAL CHARACTERISTICS AND WATER DEVELOPMENTS.

Ground water has been used for irrigation of the bottom lands of the Sacramento near Tehama, Butte City, and Colusa. The light, porous soils of the river bottoms require large heads of water in order

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to cover the land, and consequently large plants are needed. Many owners having riparian rights pump from the river with lifts about the same as those pumping from wells. The decision whether any particular tract of river bottom land should be irrigated from the river or from wells rests simply on the cost of wells relative to the cost of access to the river, the damage from floods, and losses in the ditches passing through sandy land from the river to the fields. Wells can be made cheaply by the ordinary methods as far south as Colusa, but south of this point the gravels are finer and sand screens more efficient than those customarily used should be installed.

In Solano County from the Montezuma Hills northward the size and amount of the gravels increase, and in the neighborhood of Dixon beds of rather coarse gravel are common. These gravels are mixed with sand, but include pebbles from 1 to 3 inches in diameter and are similar to those in the present bed of Putah Creek. This stream is prevented from swinging to the north by the low red hills extending south from the Hungry Hollow Hills and seems to have deposited most of its material south of its present channel. A number of dry sloughs or old channels extend southeastward from Putah Creek and are indicated by the many changes in the course of the creek in past time. Well conditions seem to be especially favorable in the triangle between Dixon Ridge, Putah Creek, and Yolo Basin.

In Yolo County, between Putah and Cache creeks, the younger alluvium is divided into east and west portions by a strip of older alluvium thrown up by the Hungry Hollow fault. The low red hills thus formed act as a partial dam to ground waters originating near Cache Creek. In consequence ground water is within 6 feet of the surface over a number of areas west of Plainfield and east of Citrona. Owing to the shallowness of the water the land is alkaline, but it affords admirable sites for pumping plants on account of the low lifts. House wells indicate that good gravel will be found. Pumping of ground water here would tend to drain and reclaim the alkaline land.

Few wells have been put down between Davis and Woodland east of the fault, but these few indicate the presence of good gravels, and the supply of water should be adequate except in the immediate vicinity of the red hills.

Large plants are characteristic of the district around Woodland and across Cache Creek on Knights Landing Ridge, where coarse, clean gravels are found at moderate depths. These gravels were deposited by Cache Creek and are widely distributed on both sides of the stream. The amount of water obtained is dependent on the thickness of the gravel bed and the kind of well screen used. For the irrigation of any particular tract prospect wells should be sunk, and when the thickness and coarseness of the gravels are learned suitable screens should be inserted, as described under "Well problems." East of

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mostly calcium and the bicarbonate radicle, and the west-side waters contain from 200 to 600 parts per million of dissolved substances, largely calcium and the bicarbonate and sulphate radicles.

2. The water table is very flat over the basins, and movements of the ground water are sluggish. Water is supplied more freely at the bases of the slopes, and for this reason the principal concentration of alkali occurs at the edges of the basins. This is particularly the case on the west side, where alkaline patches and areas of salt grass border the basin along its western edge. The distribution of alkaline land on the west side of the valley may be obtained from the soil reports of the Colusa and Woodland areas.[1]

3. The heavy winter rains leach out much of the salts concentrated at the surface. Similarly flood waters wash out the salts in overflowed lands, and on the edges of the plains the same waters deposit mud or sediment, which often covers up the alkali.

FLUCTUATIONS OF THE WATER TABLE.

The fluctuations of the water table are large. The rise begins in September and is gradual until the coming of the rains, when the rate

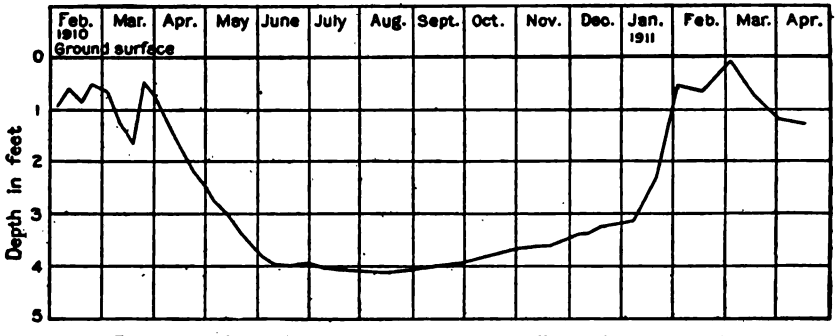

FIGURE 2.—Fluctuations of the water table in 24 wells in Colusa Basin, Cal.

increases until March. From March the water falls until, in the later part of June, it reaches the summer level, which is nearly constant except when affected by pumping. The characteristic fluctuations in the basin lands are shown in figure 2, which gives the average of the depths to water observed weekly in 24 wells in Colusa Basin. The curve is very similar to those given by Lee[2] for the moist lands in the Owens Valley. The summer low is, however, more drawn out and the rise and fall before and after the winter rains are much sharper. The rise of ground water in September before the

[1] Lapham, M. H., and others, Soil survey of the Colusa area, Cal.: U. S. Dept. Agr. Field Operations Bur. Soils, 1907, pp. 927-972. Mann, C. W., and others, Soil survey of the Woodland area, Cal.: Idem, 1909, pp. 1635-1689.

[2] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, pp. 80-81, 1912.

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winter rains seems to be due to a decrease in evaporation with cooler weather. The decreased evaporation is largely effective in the border lands. A rise of ground water in the basin areas then takes place which with lessened draft produces a general rise in all the wells of the valley.

In the plains area, where the depth to water is 15 to 25 feet in summer, the winter rise brings the water within 5 to 15 feet of the surface.

AMOUNT OF GROUND WATER.

The total quantity of ground water in the valley is very great. The sands and gravels contain from 20 to 40 per cent of water, the clays perhaps more. Because the pore spaces of the sand and gravel are much larger than those of the clay the rate of flow through these materials is much greater and they become for practical purposes the water bearers. The sand and gravels are distributed through the alluvium, which thickens from less than 50 feet at the edge of the valley to 500 feet or more in the center.

The rapidity of the winter rise and its sensitiveness to rainfall afford the best indication of the quantity of water available for pumping, for the available ground water in any district is the average amount which, falling as rain, percolates into the soil or, being collected in the mountain valleys, is carried to the plains by torrential streams and there sinks into the ground, less the amount which emerges through seepage and evaporation before or during the pumping season. It is very difficult to estimate this amount. In the neighborhood of Dixon, where pumping for irrigation had been practiced for 12 years and on a large scale for the last 5 years, water was lower in the wells in the summer of 1912 than it had been for 12 years. The water stood about 5 feet below the normal August level, according to the observations of many irrigators, necessitating the deepening of pumping pits and the lowering of pumps. This sinking of the water table was not due entirely to pumping but in part to the excess of natural loss over gain because of the small rainfall of the previous two winters. A lowering of the water level in wells, amounting probably to an average of 2 or 3 feet, had been commonly noticed by well owners throughout the valley in the summer of 1912, and it may be inferred that the additional lowering of 2 or 3 feet near Dixon in the same season was due to the withdrawal made by the hundred plants in the immediate vicinity of the town.

Changes in water level have a large bearing on the operation of pumping plants. The machinery is likely to be flooded in the spring, but in August, when water is most needed, the suction of the pumps may be so great as to decrease the supply seriously. This problem is discussed more fully under the heading "Pumping problems"

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(p. 37). The plant of T. T. Eibe, near Dixon, will serve as an example. The well is 97 feet deep and is cased to the bottom with galvanized-iron casing 10 inches in diameter. It is at one side of an 8 by 8 foot cement pit 8 feet deep and is equipped with a 5-inch horizontal centrifugal pump connected by belt in an inclined belt way to a 12-horsepower gasoline engine. When this plant was visited in October, 1912, the water stood 7 feet below the cement floor. Mr. Eibe says that it has never before been lower than 2 feet below the floor and that in the winter of 1907 it stood 2 feet from the top of the pit. Even in June, 1912, there was 4 feet of water in the pit, and in order to do any pumping it was necessary to replace the belt with a chain drive. In this place, then, there was in the dry year of 1912 a variation in level of 11 feet in less than five months. In wet years the amount of fluctuation is probably not so great because summer lowering from natural causes is about the same each year, but with increasing withdrawals of water by pumping the volume of dry ground will be increased and consequently also the absorption and storage of water during wet winters.

The winters of 1911 and 1912 were dry, less than half the normal rainfall being recorded at most of the valley stations. In consequence the winter rise of ground water was smaller than usual, and in the summer of 1913 the water table was exceptionally low. With the heavy rains of the succeeding winter, however, recovery was general, even in regions of heavy pumping.

These conditions are brought out in figure 3, which is a record of water levels in the "Irrigation investigations" well at the California University Farm at Davis. The upper curve in the figure shows the depth to the water level when the well is not in use, and the lower curve shows the depth when the pump is operated. The observations were made on the first of each month by S. H. Beckett, irrigation engineer, who generously furnished the record. The monthly rainfall at Davis, obtained from the United States Weather Bureau, is plotted for comparison.

On heavy pumping the water in a well lowers, and this lowering is called the "drawdown." The water is also lowered in the ground for some distance around the well. Wells near by are often affected and, if shallow, may be rendered useless. This depression of the water table or "cone of influence" is very large and has a flat angle when the supply of water is scanty, but is small and has a steep angle when the water is plentiful. If the ground water were simply a pool in the pore spaces of the ground this cone of influence would gradually extend and become flatter until the whole body of water would be permanently lowered, but the ground water is constantly in motion, receiving its increment from the rains and moving toward the center of the valley, where it is lost by seepage and evaporation. Its level

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rises and falls according to the amount that is passing by. When the water table at any point is depressed by pumping, movement takes

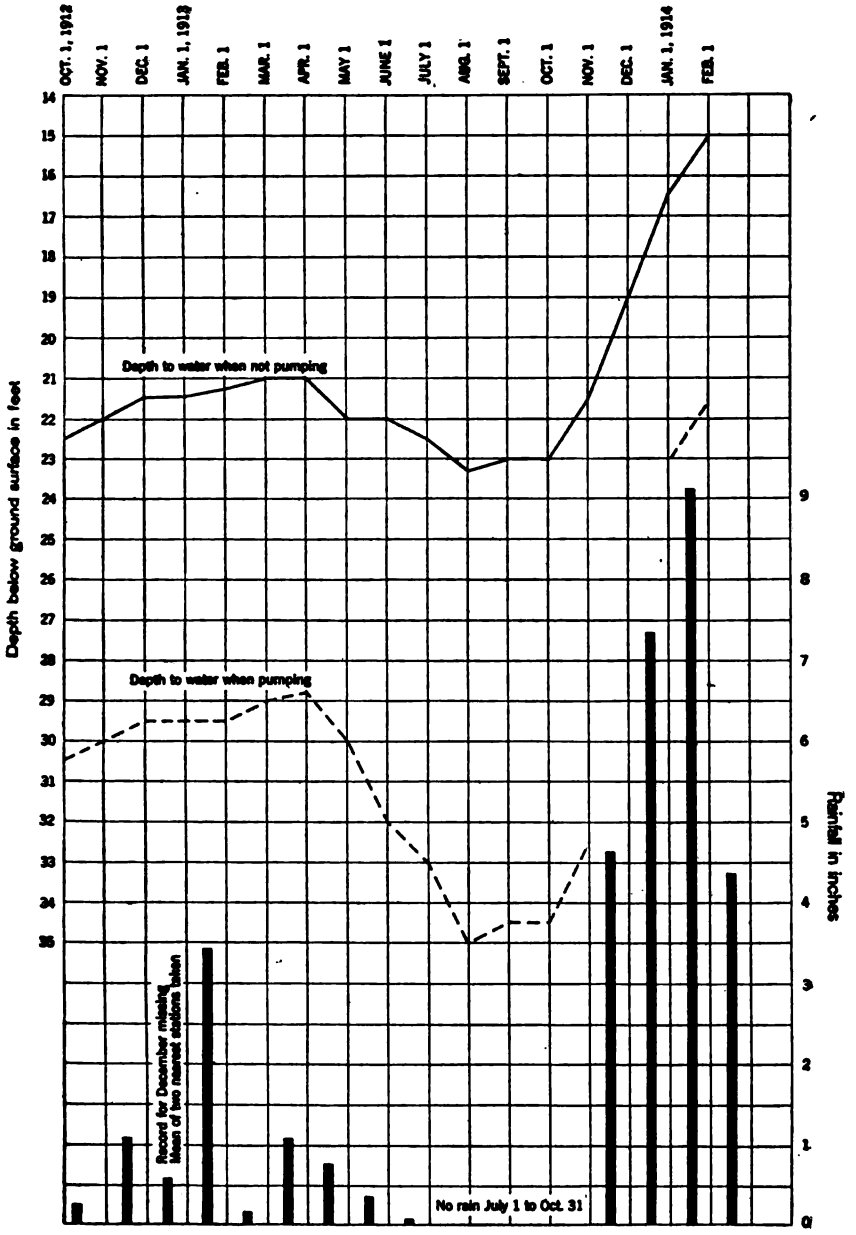

FIGURE 3.—Rainfall and fluctuations of the water table at Davis, Cal., Oct. 1, 1912, to Feb. 1, 1914. Data furnished by S. H. Beckett.

place toward that point from all directions; but the largest amount of water will come from the place where the flow originates, for on that side the head is greater.

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Figure 4 shows the position of the water table near Yuba City in September, 1913. The general slope indicated by contours from Feather River west and south to Sutter Basin is normal to the locality, though the water table is from 2 to 3 feet lower than usual because of the dry season. The principal pumping was done along Gilsizer Slough, and here the water table was lowered a maximum of about 5 feet in addition to the general lowering, as is shown by the backward swing of the contour lines. The approximate position of the water table if there had been no pumping is indicated by broken lines.

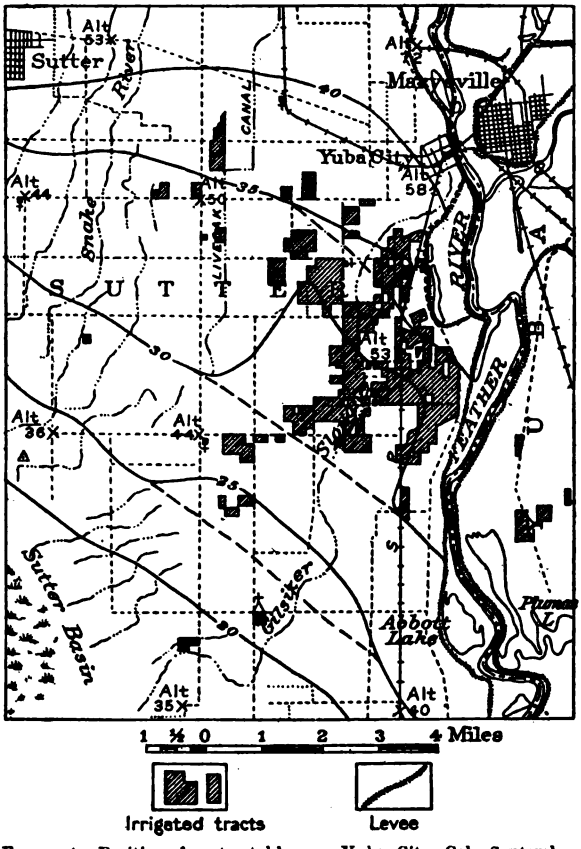

FIGURE 4.—Position of water table near Yuba City, Cal., September, 1913. Unbroken lines show contours of water table (feet above sea level); broken lines indicate probable position of contours of water table if there had been no pumping.

Similar lowering of the normal ground-water level was found along Knights Landing Ridge northeast of Yolo. The depth to water in J. R. Fisher's wells was 24 feet in July, 1900.[1] These wells were pumped with a 6-inch centrifugal pump operated by a 17-horsepower steam engine from 1898 to 1900, when the pumping plant was removed. On September 29, 1912, the water stood 23.8 feet below the top of the pump pit. Mr. Fisher stated that early in the spring of 1913 the water was only 21 feet below the surface and that in normal winters the water rises within 10 to 15 feet of the surface. On June 27, 1913, the depth to water was 39 feet. In the spring of 1913 a 3-inch centrifugal pump operated by a 10-horsepower motor was installed and 10 acres of alfalfa was

[1] Chandler, A. E., Water storage on Cache Creek, Cal.: U. S. Geol. Survey Water-Supply Paper 45, p. 25, 1901.

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GROUND-WATER DEVELOPMENT.

GENERAL CONSIDERATIONS.

The development of a pumping project has three main phases—prospecting to locate the best available water-bearing beds, sinking wells, and installing pumping machinery. Although it is possible from geologic evidence to determine for any part of the valley the general distribution and character of the water-bearing beds, the precise location of these beds and their value as sources of water can be determined only by sinking wells. Test wells should therefore be put down to determine the best place to locate permanent wells, although the advantage of having the plant at the highest point of the tract to be irrigated may cause the acceptance of poorer gravels at this point. The cost of this preliminary work is small in comparison to the cost of developing water in a poor location that is arbitrarily chosen, or in comparison to the losses that result from an inadequate supply.

WELL PROBLEMS.

DUG WELLS.

The early settlers of the valley depended altogether on dug wells, which penetrated just to or slightly below the water level. As sources of water for domestic uses most of these wells have been abandoned, because of the difficulty of keeping them in a sanitary condition.

In the development of supplies for irrigation, dug wells are suitable for obtaining the largest possible amount of water from a single water-bearing bed close to the surface. In the valleys in the older alluvium and along the foothills there are places where the principal water is in such a bed. In such places dug wells are valuable and sometimes the only suitable method of obtaining ground water, but in most parts of the valley bored or drilled wells are more satisfactory.

The two most serious difficulties connected with the sinking of dug wells are casing the sides of the hole and disposing of the water after the water level is reached, so that digging may proceed.

In most localities where such wells are valuable, as in the neighborhood of Chico, on the high plains of the east side, and in the plateau of older alluvium on the west side, the ground is sufficiently tight to stand without support until a considerable hole has been dug. In these localities a timber or concrete lining can be built in sections as digging progresses. The clays encountered on the east-side plains are so tough that they have stood in the walls of certain dug wells for 30 years without curbing. Pick marks made in digging are still visible in the walls of some of these old wells.

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a worm screw, and a chisel-bit drill. The augers vary with every outfit, and are usually made by the local blacksmith. They are from 4 to 8 feet long and from 4 to 12 inches in diameter. Hollow steel rods are used to turn the augers, to which they are connected either by a screw coupling or a square pin and socket.

In the simpler outfits boring is done by hand. One of the rods, which is kept always above ground, has a series of holes in which a horizontal drive bar is inserted. The men seize this bar and turn the auger by walking around the well. Sand and gravel are removed by the sand pump, as in ordinary cable drilling.

Within the last few years a number of power auger rigs have come into the field. There are two types—one in which a rotary plate is mounted on the ground, as in hydraulic rigs, and another with an overhead rotary. In either type a gasoline engine is mounted on the truck, which carries also a mast, or derrick, and a hoisting drum. The use of power has brought about minor modifications in the tools, but the results accomplished are about the same. The power rigs have reduced the cost of wells by reducing the labor and time required for sinking, but no reduction in price has resulted, because a better grade of work in casing and finishing a well is now required of the contractors.

Prices vary from place to place, but in general well borers charge from $1 to $2 a foot for 10 or 12 inch wells not more than 150 feet deep when the well owner pays for the casing. For the greater depths or where unusual difficulties are expected $10 a day is the usual charge.

DRILLED WELLS.

Hydraulic methods have been but little used in putting down wells in the Sacramento Valley, though there is no good reason why this method should not be suitable for sinking deep wells throughout the central and western parts of the valley.

Two types of percussion or churn drills are in use—the ordinary portable rigs of various manufactures and the California or "mud-scow" rig. The latter has many manifest advantages in unconsolidated deposits, and the double slip-joint or stovepipe casing which is used is advantageous where gravel is encountered. The ordinary portable rig is more adaptable to various conditions and can handle hard rock and cemented beds to better advantage. It has a large field of service in the east-side plains and in the areas underlaid by the Tuscan tuff.

Prices are higher for drilled wells than for bored wells, and the driller expects to put down deeper wells and do work of a higher grade. A common contract price is $1.50 a foot for the first 100 feet and an increase of 50 cents a foot for each 50 feet thereafter.

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11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in and by the cheap form of casing.

The common type of casing for bored wells is made of galvanized sheet iron (soft steel) No. 20 to No. 14 gage, though any type of casing coming in short sections may be used. Sheet-iron casing is usually riveted into 2 or 3 foot lengths by the local tinsmith or the well borer. The upper part of each joint is spread a little and the lower part contracted so that the joints can be riveted together with a lap of 1 to 2 inches. To give greater strength a band or collar 3 to 6 inches wide is sometimes used at each joint. It is then called "collared casing." Where it is desirable to exclude the upper water, the joints are soldered as the casing is put down, to make it water-tight. Perforations are made with a cold chisel or a machine punch in the flat—that is, before the flat sheets of metal are shaped and riveted into cylinders. For house wells 4 to 8 inches in diameter such casings have been very satisfactory. When inserted in gravel at a depth of 25 to 100 feet, they frequently require no perforation to furnish water for a windmill or a small centrifugal pump. Some wells so equipped have been in continuous use for 30 to 40 years, but in general such wells should not be used over 15 to 20 years without recasing. The older wells are usually found to be full of tree roots, which may form such a mat as to clog the pipe. The presence of such vegetable matter, with its consequent decay, is undesirable in drinking water, as it is liable to give the water a bad odor or taste and to induce disease.

Single casings have not been so satisfactory in wells of larger diameters. In the weights ordinarily used sheet iron is not strong enough to stand the pressures which arise when obstacles are encountered, especially if the casing has been weakened by perforation. The use of such casings in large wells intended for irrigation is too frequent and is responsible for many failures to obtain good irrigation supplies. Double slip-joint or heavy single iron, No. 12 to No. 8 gage, should be used. The disadvantages of single sheet-metal casings are as follows:

1. Single No. 20 to No. 14 sheet iron or soft steel is too weak to stand the stresses and pressures likely to be developed in inserting a casing, particularly when no drive shoe or starter is used.

2. The casing may buckle at any point, perhaps entailing the loss of the well, whereas a stovepipe casing will usually buckle at the top, where it is only a single thickness, thereby causing the loss of only the top joint.

3. The caving that often accompanies heavy pumping is likely to crush single casing and thus ruin the well.

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TYPES OF WELL SCREENS.

Success or failure in well making is dependent largely on the method of handling the water-bearing beds. Variations in the depth, thickness, and coarseness of the beds are so great and the possible combinations of these factors are so many that each well becomes a separate problem which must be solved on the ground. A description of the ordinary methods in use in the valley, illustrated by examples, together with a description of two screens not commonly used, is given in the following paragraphs. It is thought that this discussion will serve as a guide in meeting the conditions likely to be encountered in any particular well.

The common method of making a screen is to perforate the casing. It may be done before the casing is put down, but that practice is justified only when the depth and character of the water-bearing beds are known. In screw casings slots are cut with a chisel—two or three slots 2 feet long at each end of a 10 to 20 foot joint. Sheet-iron casings are frequently perforated in the flat with a hatchet or cold chisel and when riveted into pipe the burrs are turned outside. Slots are also cut out by machine punches, and by this process a larger number of holes can be cut. Casings are greatly weakened when perforated and are therefore liable to be crushed when inserted.

Perforation of the casing after it is in place is a common practice. The size and position of the water-bearing beds are noted, and after the casing is inserted slots of a suitable size are cut by perforating machines. These machines are of various local patterns, but a common form consists of a heavy frame that nearly fills the casing and is hung from the derrick by a rope or pipe line. A knife is pivoted in the frame and controlled by a second rope or pipe line. The machine is lowered to the desired place, and the slot is cut by pulling on the knife directly or by pulling the knife into position and sticking it through the casing by letting the full weight of the frame fall upon it. Skillful men working on wells that are not too deep can put from six to eight slots in a round, and one round every 6 inches in red steel slip-joint casing. The shape of the slot is governed by the shape of the knife, but very small slots are difficult to make, for a thin and consequently weak knife must be used. Slots three-eighths of an inch wide and 3 to 4 inches long are common and are suitable for the gravels ordinarily encountered.

Specially constructed well screens may be inserted in the water-bearing beds. These are of various types, but where it is necessary to obtain large water supplies from sand the wire-wrapped screen best meets conditions for the deeper wells. This screen is made by boring numerous holes in a length of pipe and then wrapping it with wire. The wire is spaced at a uniform distance, which is de-

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pendent on the size of the sand grains. Originally round wires were used, but these have been abandoned for a triangular wire which forms a slot narrow on the outside and larger within. Thus any material which passes the slot goes clear in and does not clog the screen. The spacing of the wires may be varied from one-thousandth to one-eighth of an inch. The size of the sand grains must, however, be determined by a test well, and screens of suitable sizes and lengths must be placed in the casing as it is put down. When only the sand at the bottom of a well is to be drawn on, a screen made to handle that sand may be inserted below the casing, as in oil wells. Wire-wrapped screens are manufactured under several patents and vary in detail. The approximate price may be obtained from the accompanying table extracted from a manufacturer's catalogue:

Prices of wire-wrapped strainers.

Diameter of pipe.	Price per foot.	
	Galvanized iron.	Brass.
Inches.		
5	$2.75	$3.60
6 or 6¼	3.00	4.40
7⅝	3.65	4.50
8 or 8¼	3.80	5.70
9⅝	4.00	6.00
10 or 10⅝	4.50	6.50
11⅝	5.00	7.00
12½	5.50	7.50

In the ordinary methods of screening wells the best results are obtained when the water-bearing bed is a mixture of coarse and fine material. The screen should allow the finer material to pass but hold back the coarser to form a natural screen about the well. Such a gravel screen can be obtained artificially by introducing gravel or crushed rock or tile into the hole.[1] A number of elaborate schemes have been devised for making an artificial gravel screen,[2] but ordinary conditions may be met by relatively simple devices. A sheet-iron casing 16 to 26 inches in diameter may be sunk by ordinary well methods and a thoroughly perforated casing set inside of it. The perforations in this inner casing should be large and as numerous as possible without making the casing too weak. Selected gravel or crushed rock should then be poured between the casings, and the outer casing should be gradually lifted while the well is pumped. If the gravel settles, more gravel should be added at the top until a stable condition is reached, when the outside casing can be removed entirely. Wells of this type are successful in dealing

[1] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, p. 87, 1911.

[2] Maury, D. H., Open wells and turbine pumps: Eng. News, vol. 52, No. 7, pp. 138-140, Aug. 18, 1904.

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yield of the well could be increased by lowering the pump to 18 feet, the level of ground water, and thus increasing the head under which the waters enter the well. This would involve a larger lift for the pump and consequent greater cost of operation. By increasing the capacity of the strainer and admitting the water now being held out, more water could be obtained with the same lift. With the present type of casing the number or size of the holes can not be increased materially without weakening the casing or admitting so much sand as to cause the well to cave. A common plan is to sink a new well of the same type and connect it with the plant by a suction main.

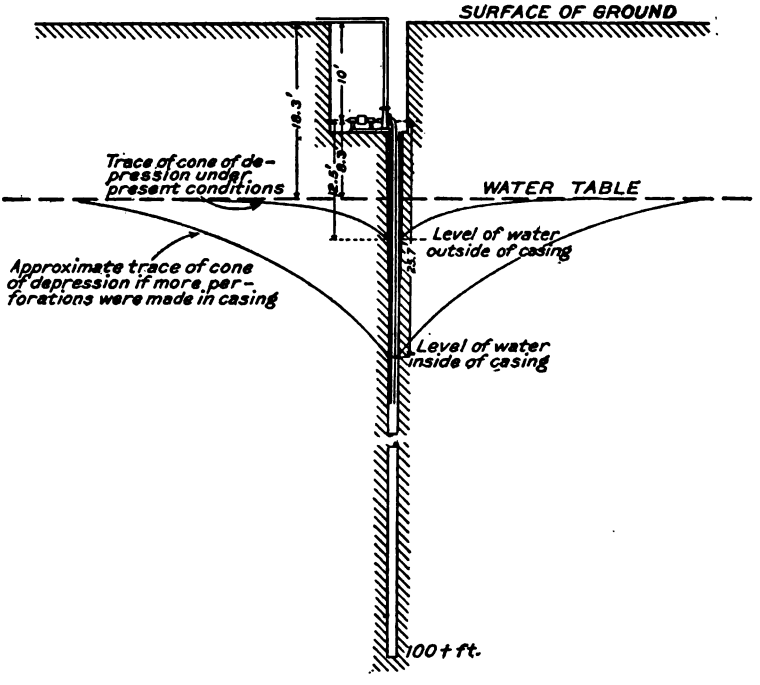

FIGURE 5.—Diagram of L. F. Torry's well near College City, Cal.

The problem may also be solved by using a more efficient strainer of the wire-wrapped type or a lining of gravel around the well, as described on pages 31–33. The first cost of wells constructed by these methods will be higher, but wells so constructed will have a longer life than wells with the ordinary single sheet-iron casing.

EFFECTIVENESS OF WELL SCREENS IN GRAVEL.

Screens made by perforations of the single or double sheet-iron casings are more effective in gravels or in sands carrying a sufficient number of pebbles to form a gravel screen around the well. The following descriptions of the Morris and St. Louis plants will bring

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out the characteristics of these screens in dealing with the thick gravel beds near Cache Creek:

The plant of Lindsay S. Morris, located 3 miles north of Yolo, is an example of good construction with single thickness casings. The plant consists of a 10-inch horizontal centrifugal Krogh pump belted to a 50-horsepower General Electric motor. The two wells are 12 inches in diameter, 50 feet apart, and 103 and 98 feet deep. Gravel similar to that which occurs in the present bed of Cache is found between depths of 58 and 114 feet, and water is drawn from this gravel only, the sand in the upper 58 feet being cased off. The casing is single galvanized sheet iron perforated in the flat by a machine punch with 333 holes $\frac{5}{16}$ by 1 inch to each 2-foot joint. Each well has 50 feet of perforated casing in the gravel. The bottoms of the wells are closed with cast cement plugs, each having eight holes $1\frac{1}{4}$ inches in diameter. The plugs were lowered into place by a bail and are designed to prevent the sucking in of gravels when pumping and yet admit sufficient water for the resulting current to prevent the accumulation of sand in the bottom of the well. The yield of the wells is estimated at 3,000 gallons a minute, or 1,500 gallons a minute each. In the season of 1913 the drawdown recorded by a vacuum gage was 27 inches of mercury, equivalent to 30.5 feet. Six-inch test wells were sunk 18 inches from each of the main wells, and on June 28, 1913, the depth to water in these wells was 24.5 feet, measured from the center of the pump, with the vacuum gage at 27 inches as before. In other words, the water outside of the casings stood 6 feet higher than was indicated by the gage for the inside. If a head of 2 feet is allowed for friction in the suction pipe, the difference in level between the inside and outside of the well was 4 feet. Further perforation of the casing to admit this water was impossible. Mr. Morris accordingly sank a 16-inch well with a similar casing between the other wells and 8 feet distant from a line connecting them. Water stood in this well, when only the other two were being pumped, 22.5 feet from the center of the pump, or 6 feet higher than the level of the other wells. This well is expected to reduce the lift and therefore the cost of pumping and to slightly increase the amount of water.

The St. Louis plant of the Sacramento Valley Sugar Co., half a mile north of Yolo, will serve as an example of good well construction with stovepipe or double sheet-iron casing. The plant consists of 12 wells set 30 feet apart in a north-south line. A 15-inch horizontal centrifugal Byron Jackson pump in a 10 by 12 foot cement pit, 17 feet deep, belted to a 150-horsepower Westinghouse motor, is located at the center of the line of wells. The suction main lies in a series of tunnels connecting the pump pit with pits 4 feet square at each well. The suction pipes are $7\frac{5}{8}$ inches in inside diameter and are

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connected to the suction pipe by a four-way union, which allows sand pumping of the wells without removal of the suction pipe. The diameter of the suction main increases from 7⅝ inches at the ends to 14 inches at the two sides of the pump. The plant discharges in two directions, east and west, to the banks of Cache Creek Slough, by riveted sheet-iron pipes. The east pipe is 18 inches in diameter and the west pipe 12 inches. The total lift is 42 feet, 15 feet discharge and 27 feet suction. The plant has a capacity estimated by C. E. Arnold, engineer for the company, at 7,000 gallons a minute.

The wells range from 98 to 107 feet in depth and tap two water-bearing gravels. The upper gravel is from 6 to 8 feet thick; below it is 20 to 22 feet of clay and at the bottom 55 to 60 feet of gravel. The casing is No. 14 gage red steel slip-joint or stovepipe casing and extends within 1 foot of the bottom of the lower gravel, the wells being open at the bottom. The perforations were made after the casing was inserted and are triangular in shape, one-half inch wide at the top and tapering out in a length of 3 inches. The attempt was made to put eight holes in a round and one round every 6 inches for the depth of the gravel. Tally of the holes actually cut gave the following results:

Record of perforations of wells of the St. Louis plant, Sacramento Valley Sugar Co., north of Yolo, Cal.

No. of well.	Depth of well.	Thickness of water-bearing gravel.	Number of perforations.	No. of well.	Depth of well.	Thickness of water-bearing gravel.	Number of perforations.
	Feet.	*Feet.*			*Feet.*	*Feet.*	
1	99	69	896	7	99	61	760
2	98	70	990	8	103	60	832
3	98	71	941	9	104	60	800
4	98	67	816	10	108	66	860
5	101	71	[a] 636	11	109	69	864
6	99	61	768	12	107	62	862

[a] About 200 more were put in but not tallied.

The perforating in these wells was done by competent workmen under good supervision, and the result may be taken as an example of the best strainer possible with casing of this type. The yield from each well is 583 gallons a minute. This compares unfavorably with the wells of the Morris plant, which yield about 1,500 gallons a minute each from gravels similar in size but in beds not quite so thick.

The wells of these plants, although they conform to the best practice characteristic of the valley, illustrate the faults common to many wells. Where a number of thin gravel beds occur the perforated stovepipe casing will be effective because its perforations will admit all the water which the beds can transmit. In thick beds of

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ordinary rancher does not expect to run his plant more than 20 days a month for 12 hours a day during the 5-month season, which would require a flow of 11.3 gallons a minute to furnish 2.5 acre-feet. Most small plants are probably in operation during an even smaller proportion of the time. At times of extreme heat the crop, particularly alfalfa, is likely to demand a quantity of water above normal, and it is therefore advantageous to have a margin of safety. The capacity should be large enough to provide water in such times of stress by pumping every day or possibly at night.

A small head is not economical in irrigating porous soils because water seeps away rapidly in such soils, and a head of water large enough to get over the ground must be used. Near Dixon, where the soil is a characteristic west-side loam, 3-inch centrifugal pumps are the smallest used and 5 or 6 inch pumps are considered the smallest practicable for irrigating alfalfa. In the Winters district, however, in the basin irrigation of orchards planted on similar land, about 400 gallons a minute, the yield of a 4 or 5 inch pump, is as large an amount as can be handled, though plants of this capacity may irrigate 100 acres. Near Corning, where the soil is tight and runs together when wet, small heads of water give the best results, and many 10-acre tracts of orchard and alfalfa are being irrigated with 2-inch pumps. Conditions somewhat similar to those at Corning prevail over the east-side plains.

In view of all these considerations a discharge of at least 12 gallons a minute to the acre should if possible be provided for alfalfa on ordinary loam soils in tracts of 40 to 200 acres, with larger capacities for smaller tracts and slightly smaller capacities for larger tracts.

In many places the problem is reversed and it is necessary to provide suitable equipment for wells of a known capacity and lift. After wells are sunk and tested, this is the problem to be solved, although in most localities in the Sacramento Valley it is possible to develop, through a series of wells, any desired capacity. The limiting factor is generally the cost, and in those localities where only small supplies are obtained by ordinary methods and with reasonable expenditure, such crops should be grown as require a minimum of water, and that in small heads.

FORMS OF PUMPS.

The centrifugal pump, because of its adaptability and ease of operation, has long been a favorite with irrigators. Modern practice in designing has increased the efficiency of these pumps, and except for extremely high lifts they are without question superior to displacement pumps for irrigation. The air lift is a device suitable for pumping from deep wells where power is furnished as a by-product

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used. This pump, with its vertical drive shaft, has the advantage that a short belt or direct drive can be used on the surface and power transmitted by the shaft. The pump will operate under water, and this is convenient where large fluctuations of the water table are likely to occur. The weight of the shaft and the end thrust must be supported by bearings, and friction losses from this cause decrease the efficiency of these installations. Top suction and a water-balance device afford some relief from end thrust. These pumps should not be used except to avoid long belts in places where the depth to water is more than 40 feet. Even for depths greater than 40 feet the direct-connected centrifugal pump or deep-well turbine should be given consideration.

Where electric power is available centrifugal pumps are often connected directly to the motor. The horizontal pump is usually built on an extended cast-iron base and the shaft is connected by a flexible leather-link coupling to the shaft of a motor set on the same base. A considerable saving in power is effected by discarding a belt, but as motors have a fixed speed depending on their make, their horsepower, and the kind of current used, each unit, whether a vertical or a horizontal pump, must be separately designed to fit the conditions under which it is to work. The manufacturers on being furnished with complete information will design a direct-connected unit and guarantee a given discharge and efficiency.

In a form of centrifugal pump that has recently come into use the shafting is inclosed in the discharge pipe and the impeller in a series of small bowls, so that the whole apparatus will fit inside a well casing. As the impellers are small a number of bowls or stages are usually provided—one to each 20 or 30 feet of lift. Diffusion vanes guide the water from one impeller chamber to the next, so that this pump is of the turbine type. It is usually called the turbine centrifugal or deep-well centrifugal. The pump is supported at the ground and hangs free in the well. Power is applied at the surface by a quarter-turn belt to a pulley on the shaft or directly by a vertical electric motor. These pumps are built in sizes from 9⅝ to 24 inches in diameter. With larger sizes a special circular steel pit to hold the pump is sunk by ordinary well methods around the well. The pit should be securely fastened to the top of the well casing. As the number of impellers can be easily increased, high heads can be handled, and the pump is proving very popular where water is deep. These pumps are also effective in obtaining maximum yields from poor wells. This is accomplished by setting the pump far below water level and pumping the water down more than is possible with the horizontal centrifugal pumps. This excessive lowering of the water level, however, causes a high lift and a heavy cost for power. Tur-

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EFFICIENCY OF PUMPS.

Manufacturers' tests of efficiency and capacity, as reported in the trade catalogues, frequently give results that can not be attained in actual practice. As a rule this is due not to any attempt by the manufacturers to deceive, but to the fact that the pumps are tested at the factory under favorable conditions that are not attained in most installations. The most important of these favorable conditions is a small suction lift. Throughout the valley suction lifts greater than those recommended by manufacturers are common, and it is a regular practice to increase the speed of the pump until the maximum suction lift, about 28 feet, results. This custom is justified during a dry season when crops demand water and the yield of the well is decreasing, but it should be practiced only in emergencies. It is more profitable in the long run to increase the supply of water by sinking more wells. It is ordinarily considered that with a centrifugal pump more than a 20-foot suction lift should not be attempted. However, high suction lifts are difficult to avoid where there are large fluctuations in the water table if horizontal centrifugal pumps, which must be kept above water, are used. Thus, if the pump is installed just above the water level in March of a wet year it will be far above the water level in August of a dry year, and high suction lifts will be unavoidable unless suitable arrangements are made to lower the pump.

Adjustments to retain the efficiency and capacity of the plant with the changing lifts due to fluctuations of the water table can be made only after the extent of these fluctuations for the locality is known. If the pump is belted to the engine or motor its capacity can be adjusted to the lift by varying the pump speed. Two sets of pulleys, one for use in the spring, when the lift is low, and the other for use late in the summer, when the lift is high, should be provided. Direct-connected outfits have a constant speed and the only means of adjusting them is to provide two impellers, one for the low lift and the other for the high lift. The saving in power that will result from such adjustments, which should be made only after consultation with the pump manufacturers, will amply repay the cost.

INSTALLATION OF PUMPING PLANTS.

After the completion of wells rough pits temporarily planked up are sufficient for testing, but when the size and type of pump are decided on a permanent pit of concrete should be built. The bottom of this pit should be at water level during the summer season, so that the pump may be set as close as possible to the water. The other dimensions of the pit depend on the size of the pump and

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whether it is belted or direct-connected. The pit should be carefully designed so as to afford working room around the pump and yet have no waste space. Dimension plates are published by all pump manufacturers, and from these the room required by the pump can be obtained. The pit may be either rectangular or circular, the circular form being slightly stronger but harder to construct. A 6-inch concrete wall without reinforcement is sufficiently strong for ordinary pits 10 to 20 feet deep. Reinforcement with woven wire or steel rods should be used in the shoulders of an inclined beltway, or the pressure of the soil will cause a failure of the wall at this point.

Bolts or timbers should be let into the side walls to facilitate the building of a stage on which to set the pump for pumping early in the spring when the pit is flooded. Another method is to make the concrete water-tight and seal the well around the suction pipe. This involves considerable expense and trouble and is not always successful. In installing direct-connected outfits means should always be provided for lifting the motor out of the pit during the winter.

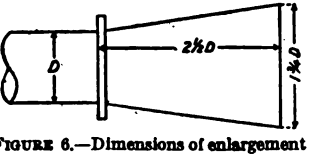

FIGURE 6.—Dimensions of enlargement of discharge and suction pipes.

When two or more wells are connected to a pump, a small pit should be constructed around each well. Except where sand occurs at water level, the cheapest method of connecting the several pits is by tunneling from one to the other. The tunnel should be supported by timber or concrete.

Large pipes should be used throughout, and in order to avoid excessive losses from friction large-angle elbows should be used. Loss of head due to friction on entrance to the suction pipe and exit from the discharge pipe may be avoided by enlarging these openings. (See fig. 6.) The enlargement should not be abrupt but gradual. The following rule is given by Gregory:[1] The diameter of the end should be 1¾ times that of the pipe, and the enlargement should begin at a distance from the end 2½ times the diameter. The discharge pipe should lead to the bottom of a cement trough of large size. The trough should lead to the ditch without any drop or waste head. Probably 50 per cent of the existing plants pump water from 1 foot to 6 feet higher than is necessary.

A suitable house should be built over the plant to protect it from the weather. This should be done the first season, for a few grains of sand or a little rust may do irreparable damage.

[1] Gregory, W. B., The selection and installation of machinery for small pumping plants: U. S. Dept. Agr. Office Exper. Sta. Circ. 101, 1910, p. 19.

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DISTRIBUTING SYSTEMS.

Only a few of the plants in the valley have an adequate system of distribution. Crude earthen ditches are sufficient in tight soils, but in the loams of the west side and the river bottoms the loss by seepage in such ditches is great, and most of the water that is lost percolates downward and is of no value to the crop. The relatively tight soil of the Richfield tract, north of Corning, showed a loss of 17 per cent to the mile with a stream of 1,100 gallons a minute. In loam soils the loss often amounts to as much as 20 per cent in half a mile.

The use of cement pipe will prevent these losses and also bring about a saving of land and a reduction in the cost of irrigation. A comprehensive account of the manufacture and cost of cement pipe in southern California is given by Tait,[1] from whose paper the following table of costs is taken:

Cost of cement pipe at Pomona, Cal.

Size.	Cost per foot.	Cost per foot laid.
Inches.		
8	$0.12½	$0.17
10	.16	.22
12	.22	.32
16	.35	.50

The cost of pipe in the Sacramento Valley, based on work done for the Mills Orchard Co., at Hamilton, is given by Mills [2] as follows:

Cost of concrete pipe in Sacramento Valley.

Size.	Cost per foot.	Size.	Cost per foot.
Inches.		*Inches.*	
8	$0.28	18	$0.65
10	.35	24	.84
12	.43	30	1.10
16	.56	36	1.55

These prices are for "wet-tamp" pipe, 1 part cement to 4 parts "gravel," the latter being the natural mixture found in streams, about 2 parts sand and 2 parts gravel. These estimates are based on cement at $2.50 a barrel and gravel at 15 cents a cubic yard, both delivered at the pipe yard, and also allow for hauling the pipe from the pipe yard, an average distance of 1 mile. The cost of laying pipe is included, but not the cost of overflows, standpipes, valves, etc.

[1] Tait, C. E., The use of underground water for irrigation at Pomona, Cal.: U. S. Dept. Agr. Office Exper. Sta. Bull. 236, pp. 56–60, 80–83, 1912.

[2] Mills, E. C., Concrete pipe and overflow basins for distributing irrigation water: Eng. Record, vol. 67, No. 24, p. 652, June 7, 1913.

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It is believed that these costs will be reduced as the demand for pipe increases. Certainly it should be possible to manufacture pipe as cheaply in the Sacramento Valley as in southern California. It is reported that some contractors are ready at the present time to make a price of 35 cents a foot for 12-inch pipe.

John Borgman, a rancher near Nicolaus, says that 2,000 feet of 12-inch pipe on his ranch cost less than 25 cents a foot. This pipe was laid continuously in a trench by the use of a form consisting of a 4-foot length of 12-inch galvanized pipe fitted with a handle in one end. The trench was carefully shaped, rounded on the bottom, and 15 inches wide. A layer of concrete 1½ inches thick was put in the bottom of the trench and the form was laid on top and covered with strips of burlap. Wires 14 inches long were bent over the form and thrust into the concrete on both sides. Concrete was then laid over the form for a depth of 2 inches. As soon as the next 4-foot bed of concrete was ready the form was slipped out and forward. The burlap strips allowed the form to slip out, and the wire reinforcement was sufficient to hold up the arch. Mr. Borgman and his son, after they became skillful, laid from 80 to 90 feet of pipe a day. The occasional leaks were not serious, but it was found that a mixture of 1 part cement, 2 parts sand, and 2 parts gravel was necessary to prevent seepage through the walls. Although pipe cast in molds is preferable for strength and adaptability and has the advantage that it can be easily inspected for defects, it is thought that the method devised by Mr. Borgman, with such simple adaptations as will occur to the irrigator, will enable men of small capital to equip their ranches with an effective pipe system.

IRRIGATION WITH WELL WATER.

Progress in irrigation has been rapid in the Sacramento Valley within the last few years, the principal development being in private irrigation plants using ground water. Most of the plants are situated in groups around the towns, partly because of economic reasons and partly because irrigation is infectious and the installation of one plant makes converts among the neighbors.

Statistics of irrigation were collected in the summer and fall of 1912 for the region west of Sacramento River between Willows and Rio Vista, and in the summer and fall of 1913 for the rest of the valley except Sacramento County. By correspondence and a short trip in 1913 the west-side material was brought up to date, so that the figures in the accompanying table represent conditions in 1913. Two short trips into Sacramento County were made by the writer in 1913 and 1914. In the winter of 1914 J. W. Muller, of the Geological Survey, spent two months collecting statistics of pumping. The figures for

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the Sacramento area and the southern part of the Bear-American River area are the result of his work and cover the season of 1914.

An attempt was made to visit each pumping plant and to determine the area actually irrigated. Some difficulty was found in determining what should be considered a pumping plant for irrigation. In many places there are plants with 2-inch pumps and 5-horsepower engines used to obtain water for stock and domestic purposes and for watering lawns and house gardens which were not considered as irrigation plants, but plants of the same size near Corning that are used for irrigating commercial orchards were listed as irrigation plants, though they are also used for domestic purposes. In the Sacramento area the combined suburban home and small farm is so common that practically all plants are listed. Irrigation was credited to a plant only where there was local evidence of irrigation at the time the plant was visited or where information that the plant was so used was deemed reliable. Proposed irrigation was rigidly excluded from the statistics.

The installed plants and acreage irrigated in 1913 (Sacramento County figures are for 1914) are presented in the following table, which is subject to minor revision. In this table the valley is divided into 19 areas in which pumping is concentrated in groups. These areas, the boundaries of which are arbitrary, are shown on the map of the valley (Pl. II).

Statistics of ground-water irrigation in the Sacramento Valley for 1913.

Area. (See Pl. II.)	Number of plants.	Number of owners.	Area irrigated.	Nominal electric power.	Nominal gasoline, oil, and steam power.	All power.	Average power per plant.	Average area irrigated for each plant.	Average area irrigated for each horsepower.
			Acres.	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Acres.*	*Acres.*
Red Bluff-Tehama	25	8	1,387	297	30	327	13.0	55.4	4.2
Chico	16	15	1,345	375	34	409	25.5	84.0	3.3
Butte City	7	5	470	45	30	75	10.6	68.2	6.2
Gridley and Marysville Buttes	5	5	115	105	15	120	24.0	23.0	.9
Oroville-Marysville	23	23	370	150	39	189	8.2	16.1	1.9
East Sutter Basin	167	126	4,144	1,106	195	1,301	7.7	24.8	3.2
Yuba-Bear River	22	19	607	175	52	227	10.3	27.5	2.6
Bear-American River[a]	81	77	1,450	129	530	659	8.1	17.9	2.2
Corning	84	66	1,780	483	73	556	6 6	20.2	3.2
Hamilton-Orland	14	11	1,405	160	45	205	14.6	100.3	6.8
Willows	67	46	2,431	575	122	697	10.4	36.2	3.5
Williams	15	13	280	100	63	163	10.8	18.6	1.7
Colusa-Meridian	14	14	529	165	139	304	21.7	37.7	1.7
Arbuckle	7	7	70	.....	28	28	4.0	10.0	2.5
Woodland	37	26	7,988	1,812	140	1,952	52.7	215.8	4.1
Esparto-Madison	10	10	148	25	60	85	8.5	14.8	1.7
Davis-Winters-Dixon	128	111	5,696	1,302	529	1,831	14.3	44.5	3.1
Rio Vista	3	3	19	20	4	24	8.0	6.3	.8
Sacramento[b]	939	837	10,625	3,061	2,329	5,990	6.3	11.3	1.7
	1,664	1,422	40,859	10,685	4,457	15,142	9.1	24.5	2.7

[a] Collected in part by J. W. Muller in 1914.
[b] Collected by J. W. Muller in 1914.

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Of the total horsepower used 70 per cent is electric; the rest is developed by internal-combustion engines and by a few steam engines in old plants. High-tension electric-power lines of several different companies cross the valley to the bay cities from water-power plants located in the Sierra Nevada. Local power lines at lower voltage run out through the country from numerous transformer stations on the main lines. Those areas in which the power produced by gasoline, oil, and steam engines equals or exceeds the electric power have scattered plants, many of which are far from power lines. The large use of gasoline power in the Davis-Winters-Dixon area is due partly to the fact that a number of plants were installed before electric power was available and partly to a belief that gasoline plants are cheaper.

The average horsepower to a plant is 9.1, and the average area irrigated 24.5 acres, or 2.7 acres for each horsepower used. Wide variations in the size of the plants and the acreage per horsepower exist in the several districts. They are not due primarily to differences in lift, for the lifts do not vary much from one district to the other, but to differences in soil and crops and in the size of farm units. The Butte City and Hamilton-Orland areas have a large acreage per horsepower because of the economical irrigation of young orchards by large companies. The East Sutter Basin area is also predominantly an orchard district, but the plants supply small tracts because the land is in small blocks and each owner irrigates only his own land. Relatively large heads of water are, however, required in this area to cover the ground, and therefore small plants are not practicable. Economy could be effected by cooperation between neighbors. The use of one plant by several ranchers would reduce the interest and depreciation charges, which form so large a part of the cost of pumped water.

The average irrigation in all areas is brought down by the inclusion of plants recently installed, which irrigated only small tracts in the following year. An effort should be made when a new plant is installed to complete the grading and checking of the land so that the plants can be brought into full use without undue loss of time.

The machinery installed in the pumping plants of the valley is capable of a certain amount of work, which can be estimated for assumed conditions and compared to the actual results in acreage irrigated. While no large series of tests have been made, it may be assumed that the plants have an over-all efficiency of 40 per cent—that is, that 40 per cent of the nominal horsepower of the motors and engines is actually effective in lifting water. This figure is assumed on the ground that the large number of direct-connected electric units of high efficiency will balance the plants of low efficiency. The

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average lift may be taken at 40 feet, which is perhaps a high rather than a low figure.

The average of 9 horsepower to the plant, as given in the table (p. 46), with a plant efficiency of 40 per cent and a lift of 40 feet, will deliver 358 gallons a minute. On page 38 it is stated that the time a plant ordinarily runs is 12 hours a day and 20 days a month for 5 months. With this pumping time 11.3 gallons a minute is necessary to furnish 2.5 acre-feet an acre for the season, which is nearly the right figure for alfalfa, though much too high for orchards. This pumping time is based on five irrigations of 6 inches each, which is common on alfalfa. However, the irrigations are not always evenly divided, the third and fourth irrigations often being much heavier than the others. A discharge of 11.3 gallons a minute to the acre will allow 7½ inches to be applied in 28 days' pumping, 12 hours a day. Heavier irrigations are seldom necessary but can be provided by night pumping. The time required for one irrigation can also be reduced by operating the plant for a longer time each day. The necessity which may arise at certain times for large applications of water and for getting a field irrigated quickly in order to keep the crop growing justifies large installations. The intelligent irrigator will, however, attempt to reduce the peak load on his irrigation plant by adjustments of his system of agriculture in order to use as small a plant as is possible.

At 11.3 gallons a minute to the acre a discharge of 358 gallons a minute (from a 9-horsepower plant) for 12 hours a day will irrigate 31.6 acres with 2.5 feet of water for the season. By increasing the pumping time to 16 hours a day for the 100-day season, the same discharge will irrigate 42.3 acres with the same amount of water. With this increased pumping time and a reduction in the amount of water applied from 2.5 feet to 2 feet the same plant will supply 52.8 acres.

While 24.5 acres, the average acreage to the plant derived from the statistics (p. 46), is a rough figure and includes many different kinds of plants pumping on different kinds of crops, it is so near the figure, 31.6 acres, obtained by assuming the conditions stated above in full that it indicates either that the valley plants are fairly efficient and well used or that the assumptions do not represent average conditions as to lift and duty of water. It will be seen from the following analysis that the assumptions are good for an average plant irrigating field crops. Many plants have low lifts or irrigate orchards and do not comply with the assumptions. In irrigating porous soils a discharge as small as 358 gallons a minute is easily lost by seepage and will not irrigate as much land as the figures call for. The large increase in acreage with increased running time is exceedingly significant. Analysis shows that the average area irrigated by each plant can be

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GROUND WATER IN PARADISE VALLEY, ARIZONA.

By O. E. Meinzer and A. J. Ellis.

INTRODUCTION.

Paradise Valley is situated north of Phoenix, in Maricopa County, Ariz. (see fig. 7), between the Phoenix Mountains on the west and the McDowell Mountains on the east. At the north end it is terminated by a rocky upland, but on the south it opens into the Salt River valley. If the Arizona canal is taken as its southern boundary, it is approximately 20 miles long and 10 miles wide and has an area of about 200 square miles. Cave Creek, an intermittent stream that drains about 225 square miles of mountainous country north of Paradise Valley, formerly no doubt flowed southward through Paradise Valley but now flows across only the northwest corner of this valley and reaches the Salt River valley through a gap in the Phoenix Mountains and through Deer Valley, which lies west of these mountains. (See Pl. III.) Paradise Valley is closely related to Cave Creek in both its physiographic history and its ground-water supply, and the entire drainage basin of Cave Creek is therefore included in the area discussed in this paper.

The present population of the area under consideration consists of a number of recent settlers in Paradise Valley south of the old Verde canal (see Pl. III), a few old settlers and homesteaders in the vicinity of Cave Creek station, and a number of miners and prospectors at the Union mine and elsewhere in the mountains. A stage that carries the mail runs from Phoenix to Cave Creek station by way of Montgomery and the Union mine. The distance by wagon road from Phoenix to Montgomery is 12 miles, and the distance from Phoenix to Cave Creek station is 29 miles. Scottsdale, which contains a post office, a general store, and a telephone office, is situated immediately south of the Arizona canal and is easily reached from the southern part of the valley.

One of the most notable features of Paradise Valley is the abandoned Verde canal, which lies just above a large tract of excellent agricultural land in the heart of the valley and which, although now of no practical value, gives a powerful stimulus to the imagination of one who is endeavoring to visualize the transformation that could be wrought in this part of the valley if an adequate water supply were

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the Arizona Agricultural Experiment Station by Mr. A. E. Vinson, through the courtesy of Mr. R. H. Forbes, director.

PHYSIOGRAPHY AND DRAINAGE.

Paradise Valley lies between the Phoenix and McDowell ranges and occupies a troughlike depression that has been partly filled by unconsolidated rock débris washed from the mountains. It appears to belong to the desert region rather than the mountain region, as described by Ransome.[1] (See fig. 7.)

The McDowell Mountains form an unbroken range extending from the Salt River valley nearly to the Camp Creek road, shown on the map (Pl. III), and in McDowell Peak they reach an elevation of 4,022 feet above sea level. The west flank of this range is about 3 miles wide and is gashed by numerous small canyons which during wet seasons discharge storm waters into Paradise Valley, but it contains no permanent streams and, so far as was ascertained, no spring except Frazer Spring, shown on Plate III. At its south end the range is surrounded by valley fill, but to the north and northwest it is bordered by an extensive plateau underlain by bedrock or covered with only a thin mantle of rock waste. This rock-floored plateau, lying between the north end of the McDowell Mountains and a group of conspicuous peaks in the vicinity of Cave Creek, rises gently toward the northeast and forms an extension of the smooth constructional surface of the valley, although cut to a greater extent by gullies. Its width in the direction of the drainage lines is about 8 miles, and it therefore discharges a large amount of storm water into the valley.

Farther north and northwest there is an area of about 225 square miles of hills and ridges which was not examined except near its south end but which is known to be tributary to Cave Creek. (See Pl. III.) Cave Creek is normally dry but has an underflow that appears at the surface at Cave Creek station and sinks to unknown depths a short distance below the station. The creek carries large quantities of water after heavy storms of the summer rainy season and during parts of the winter season. The magnitude of the largest floods is shown by the broad streamway, the long distance that bowlders have been transported, and other evidences of high water. It is said that in exceptional freshets the water from Cave Creek has flooded parts of Phoenix.

The Phoenix Mountains, which lie west of Paradise Valley and extend from the Arizona canal northwestward to the mountainous region above Cave Creek station, rise abruptly from the valley floor but reach elevations of only 2,000 to 3,000 feet above sea level. This low range has no washes of considerable size that discharge into

[1] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (No. 112), p. 1, 1904.

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quartz, and biotite, which yields readily to weathering. These formations constitute the rock rim which incloses Paradise Valley, and they probably extend under the fill, forming the rock floor of the valley itself.

Quaternary deposits (valley fill).—The valley floor is the surface of a fluviatile deposit of unconsolidated arkosic or partly decomposed rock débris, with lenses of gravel and clay. This deposit has been derived from the adjacent mountains and especially from the region lying north of the valley. The fill increases in thickness southward from the outcrop of the bedrocks in the north and reaches a great depth in Salt River valley. None of the borings in the middle of Paradise Valley have reached bedrock, although some of them extend to depths of several hundred feet (see table, p. 70), and the maximum depth of the fill is therefore unknown.

Where Cave Creek crosses the northwest corner of the valley, about 10 feet of loosely cemented conglomerate which contains bowlders as much as 12 inches in diameter is exposed in the creek bank. (See Pl. III and Pl. V, *B*, pp. 52, 56.) Similar beds have been encountered in some of the wells in the southern part of the valley at various depths from 100 to 300 feet or more. In Henry Crowe's well, in the interior of the valley (No. 31, p. 70, and Pl. III), bowlders several feet in diameter are said to have been reached. These deposits probably mark former courses of Cave Creek at times when its transporting power was unusually great, but they may have been in part deposited by lateral streams or wash from the Phoenix or McDowell mountains.

Caliche, or lime hardpan, is exposed in the marginal parts of the valley and was encountered in wells in the interior of the valley. Some wells penetrate several layers of caliche that are separated from one another by deposits of less thoroughly cemented valley fill.

SOIL AND VEGETATION.

The soil over most of the valley is a brownish loam, generally containing a few pebbles and small fragments of such rocks as those surrounding the valley. It is of good physical constituency and would no doubt make fertile soil for agriculture. Adjacent to the mountains there is a narrow belt of coarse gravelly soil which is not sufficiently disintegrated to be suitable for cultivation.

Mesquite, creosote bush, and palo verde make up in large part the flora on the loamy soil, and cacti of various species, including the giant cactus and the cholla, occupy the gravelly soils at the margins of the valley and on the adjacent uplands. (See Pl. IV.) Except for the cacti the mountains support only very sparse vegetation. In general mesquite and palo verde grow in this valley to heights of only 5 or 6 feet, but some of them in the vicinity of stream courses

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A. SOIL AND VEGETATION OF GRAVELLY UPLANDS AT NORTH EDGE OF PARADISE VALLEY, ARIZ.

B. SOIL AND VEGETATION AT INTERMEDIATE LEVELS IN PARADISE VALLEY, ARIZ.

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lowest temperature at Phoenix during the same period was 30° F., but the complete record shows that at Phoenix the temperature falls to 25° F. or lower during normal winters, and it is therefore probable that temperatures of 20° to 25° F. are reached in normal winter

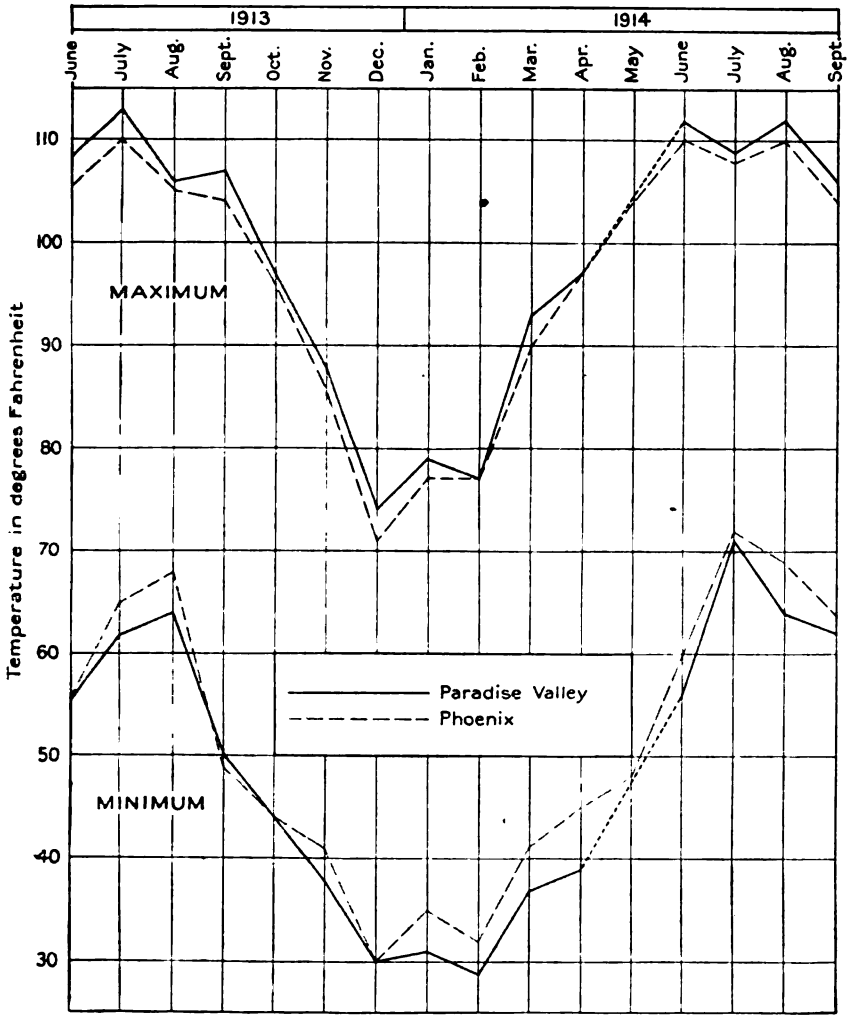

FIGURE 9.—Diagram showing relation between maximum and minimum monthly temperatures in Paradise Valley and Phoenix during months in which observations were made at both places.

seasons in Paradise Valley. The minimum winter temperatures at Phoenix, according to records extending over the period from 1909 to 1914, inclusive (see fig. 10), are only slightly lower than those at Redlands, Cal., where the climatic conditions are eminently suitable for the culture of citrus fruit.

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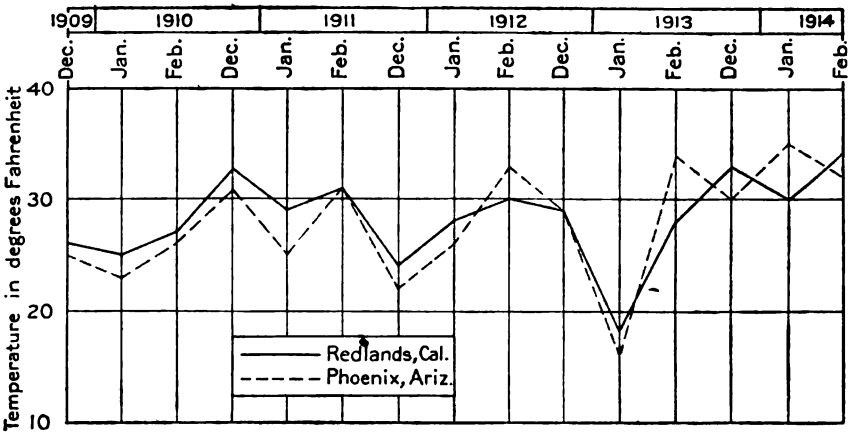

FIGURE 10.—Diagram showing relation between minimum temperatures in December, January, and February, 1909–1914, at Phoenix, Ariz., and Redlands, Cal.

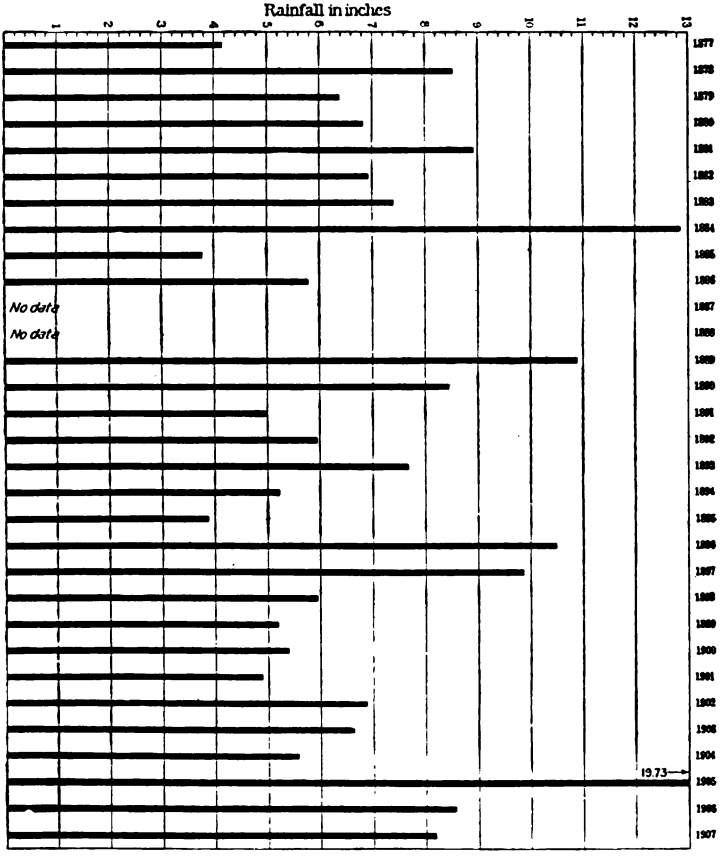

FIGURE 11.—Diagram showing total annual rainfall for 29 years, 1877 to 1907, inclusive, except 1887 and 1888, at Phoenix, Ariz.

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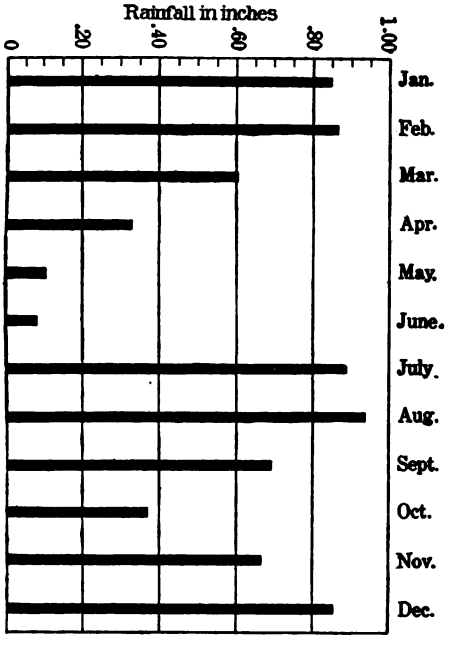

FIGURE 12.—Diagram showing mean monthly rainfall at Phoenix, Ariz. Length of record, 32 years—1876 to 1907.

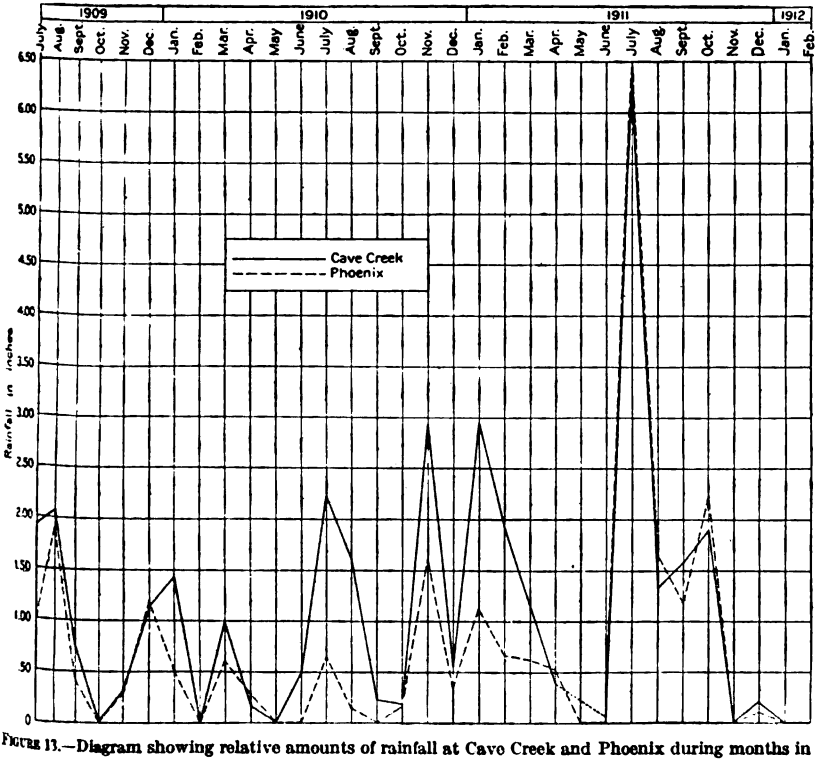

FIGURE 13.—Diagram showing relative amounts of rainfall at Cave Creek and Phoenix during months in which observations were made at both places.

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The total annual rainfall at Phoenix, as determined by observations extending over a period of 29 years, ranges from 3.77 to 19.33 inches and averages 7.27 inches. (See fig. 11.) The mean monthly rainfall, as shown in figure 12, ranges from 0.08 to 0.94 inch, the minimum occurring in June and the maximum in August. A comparison of the rainfall at Phoenix with that at Cave Creek (fig. 13) shows a somewhat greater rainfall at Cave Creek. The same relation is shown in a comparison of the Paradise Valley record with that

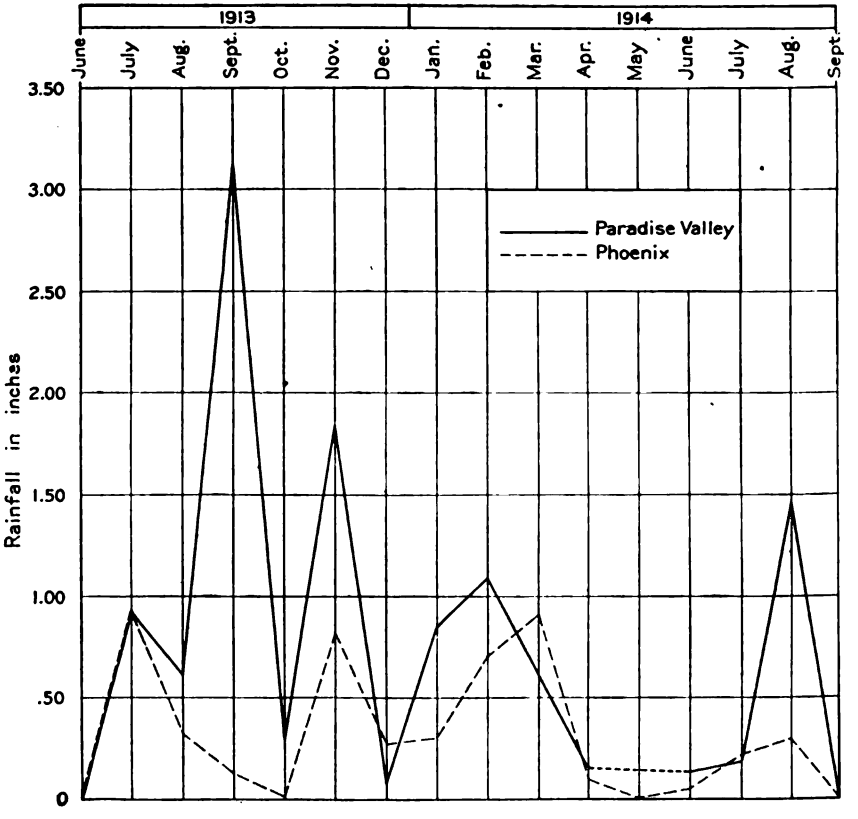

FIGURE 14.—Diagram showing relative amounts of rainfall at Paradise Valley and Phoenix during months in which observations were made at both places.

of Phoenix (fig. 14). The total rainfall recorded during the period of observations was for Paradise Valley 11.89 inches and for Phoenix 5.09 inches, a difference of 6.80 inches, but these figures are based on so short a record that they can not be said to represent general conditions.

OCCURRENCE OF GROUND WATER.

Paradise Valley occupies a rock trough partly filled with detritus which in its lower portion is saturated with water. The inclosing bedrock is practically impervious, its pore spaces being small and its

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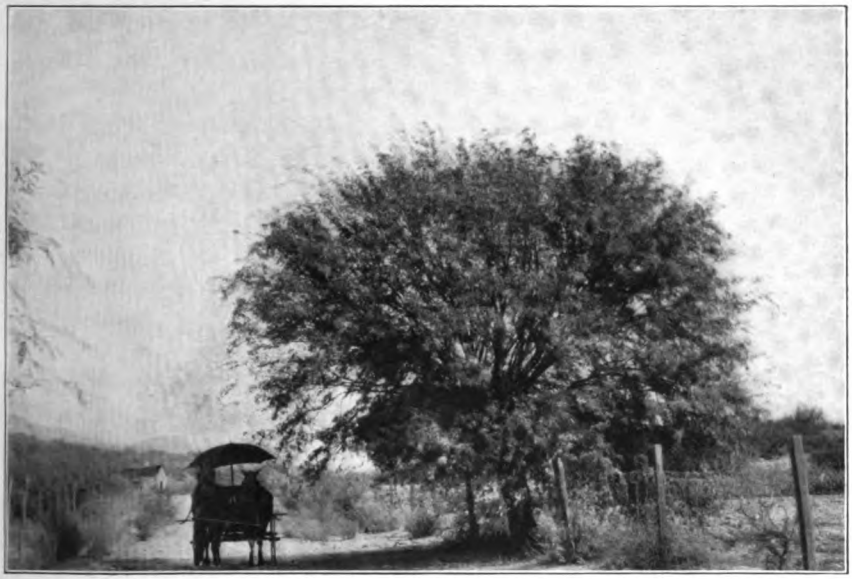

A. LARGE MESQUITE TREE WATERED BY UNDERFLOW OF CAVE CREEK, PARADISE VALLEY, ARIZ.

B. BANK OF CAVE CREEK IN PARADISE VALLEY, ARIZ., 6 MILES BELOW MOUTH OF CANYON, SHOWING CONGLOMERATE THAT FORMS GROUND-WATER INTAKE.

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from the water that percolates downstream through the coarse detritus in Cave Creek canyon. Although this underground stream is small in volume compared with the surface streams, its relative importance as a source of ground water is probably not so small, for its flow is perennial, whereas the surface streams are temporary, and moreover its flow is apparently all contributed to the underground reservoir of Paradise Valley, whereas the proportion of the flood waters contributed is uncertain.

During the ages that Paradise Valley was gradually being built up by the deposition of rock detritus the course of Cave Creek through it must have been marked by beds of gravel which are now deeply buried but which head at the mouth of Cave Creek canyon and are therefore still in a favorable position to convey Cave Creek water. The lower part of the valley is two to three times as far from the mouth of the canyon as the point where the coarse gravel bed shown in Plate V, *B*, was observed, but in view of the facts that this gravel is very coarse, that gravel occurs much farther downstream, and that the gradient of Paradise Valley was no doubt steeper before so much filling had taken place than it is at present, it seems probable that the detritus along the ancient channels of the stream was coarse enough to be good water-bearing material even at the south end of the valley. This view is corroborated by the beds of gravel encountered in drilling.

If the average annual precipitation in the Cave Creek drainage basin above Cave Creek station is 10 inches the total quantity of water that falls on this basin in an average year is about 120,000 acre-feet. No data are available as to how much of this water is poured into Paradise Valley, and no estimate can be made of the proportion of it that is contributed to the underground supply. If only 1 per cent of the rainfall on the Cave Creek basin is converted into ground water underlying Paradise Valley the annual ground-water supply from this source is only 1,200 acre-feet; if 10 per cent is thus converted the annual supply is 12,000 acre-feet.

Owing to the impervious character of the rocks a large part of the water that falls as rain on the McDowell Mountains and other upland areas directly tributary to this valley is shed into the talus at the foot of the mountains or into the coarse fill near the margins of the valley and finally reaches the main body of ground water. On account, however, of the low rainfall and the small extent of the mountain areas, exclusive of the Cave Creek drainage basin, that are tributary to the valley, the amount of water received from this source is doubtless rather small.

Some of the water which falls as rain on the valley surface is also added to the body of ground water, but as the fill in the interior of the valley is rather compact and considerably cemented the contribution from this source may not be very large. Much of the water is

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absorbed by the dry soil and descends only a short distance. After the rainstorms it is returned to the surface by capillarity and there evaporated, or taken up by the roots of plants and restored to the atmosphere by transpiration.

The processes by which ground water escapes from an area are seepage into streams, evaporation from shallow-water tracts, transpiration, underflow, and seepage into bedrocks. To these natural processes must be added artificial removal through wells. In this valley the main body of ground water is too far below the surface to suffer losses by seepage into streams, evaporation, or transpiration, and owing to the impervious character of the bedrocks absorption by them can not be regarded as a considerable loss. The amount of water pumped is as yet also a negligible quantity. The gaps in the rock wall on the west side are probably not deep enough to extend below the water table, but the structure of the valley is favorable for free underflow southward into the Salt River valley. That there is such an underflow and that there is no underflow from the Salt River valley into Paradise Valley is also shown by the southward slope of the water table and by the much greater mineralization of the ground water in the Salt River valley than in Paradise Valley. (See pp. 67, 69.) The fact that the slope of the water table averages only about 5 feet to the mile in areas where data were obtainable indicates either that the water-bearing beds are very porous or that the annual recharge is small.

ARTESIAN PROSPECTS.

The character and structure of the bedrocks that are adjacent to Paradise Valley and that presumably underlie the valley fill render these rocks absolutely hopeless as a source of artesian water. All the requisite conditions for flowing wells are absent, as is very obvious from the description of the rocks on page 55.

The structure of the valley fill is such as to allow some of the water to acquire a small amount of head, but there is practically no prospect of obtaining flowing wells from the fill. In nine of the fifty wells in Paradise Valley concerning which information was obtained the water is known to have risen from 1 to 10 feet above the levels at which it was first struck. Such small rise is found in the fill of practically all western valleys that have been investigated. It may be explained in a general way as due to differences in the porosity of successive layers of fill and in the resistance of the water-bearing beds to the percolation of the water. Thus if the fill is traversed by buried gravelly channels of Cave Creek, as suggested on page 56, these old channels may be regarded as tubes that conduct water from the high levels of the northern part of the valley to the low levels of the southern part. Owing to the resistance to percolation by the

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WELLS.

In the last few years more than 50 wells have been sunk in Paradise Valley south of the Verde canal. Most of them were drilled by means of standard rigs and have diameters of 6 or 8 inches, but a considerable number were dug by hand and are several feet in diameter. Both in digging and in drilling wells it was found that the valley fill is sufficiently coherent to stand without curbing, and it is therefore customary to use only a few feet of casing in the tops of drilled wells. It would, however, be better practice to line the entire well with at least a sheet-metal casing in order to prevent deterioration by caving. On the whole, the wells do not extend far enough below the water table and have not been pumped hard enough to give an adequate test of the ground-water possibilities. For a discussion of irrigation wells, see page 72.

Detailed information in regard to the wells examined is given in the following table and the appended notes:

Records of wells in Paradise Valley.

Number on map.	Owner.	Location.				Kind of well.	Depth of well.	Depth to water level.	Diameter or cross section.	Yield per minute.
		Quarter.	Section.	Township north.	Range east.					
							Feet.	*Feet.*		*Gallons.*
1a	J. D. Houck	SE	29	6	4	Dug	16	12	5 by 5 feet	
1b	do	SE	29	6	4	do	6	4	4 by 4 feet	
2	E. A. Howard	SW	28	6	4	do	(a)			
3	W. H. Rheimer	SE	28	6	4	do	23	22		
5	C. B. Williams	SW	30	4	4	Drilled.	310	272	6 inches	5
6	—— Tymack	NE	5	3	3	do	200+			Low.
7	George O'Clair	SW	1	3	3	do	300	195	6 inches	20
8	Harvey Bell	NE	6	3	4	do	251	237	do	
9	—— Lyman	NE	8	3	3		280			
10	—— Hall	SE	9	3	3		160			
11	—— Nesbit	NE	11	3	3	Drilled.	235	200		
13	J. Lammers	SE	11	3	4	do				
14	—— Langley	NW	12	3	4		273	232		
15	S. L. Montgomery	SW	14	3	3	Drilled.	225	196	6 inches	18
16	—— Allec	NW	13	3	3		198	75		
17		(b)	13	3	3		400+			
18	—— Engel	Center	13	3	3		163			
19	—— Lynn	SW	15	3	4	Dug	176	173		
20	—— Pepper	NE	15	3	4		200	185		
21		NW	14	3	4	Drilled.		184		
23		NW	22	3	4	Dug	c 100			
24	J. R. Brock		22	3	4	Drilled.	532	157		
25		NE	23	3	4	do				
26		NW	24	3	4	Dug	c 60		4 feet	
27	Jasper Morgan	(d)	24	3	4		200	180+		
28	J. N. Green	SW	27	3	4	Drilled.	175	145		
29	Miss Green	NE	27	3	4	do	160	130		
30	—— Hover	NW	26	3	4	do	257	145		
31	Henry Crowe	(e)	26	3	4	Dug 146, drilled 100.	246	145		f 40
32	H. E. Pierce	NW	30	3	5	Drilled.		150	6 inches	
33	S. A. Allen	NE	30	3	5		198	180		
34	J. W. Smith	SE	33	3	4	Drilled.	141	102	6 inches	f 10-12
35	R. W. Cowey	NW	34	3	4	do	147	111		
36	Kelley Wright	SW	35	3	4		205			
37	A. Showers	NE	35	3	4	Dug 120, drilled 180.	300	108		

a Shallow.
b Middle of north margin.
c Well not completed.
d East central part.
e North central part.
f Reported by the drillers.

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in diameter. Pumping plant consists of single-acting cylinder pump in each well, both operated by gasoline engine. The two wells are said to have been pumped continuously for 5 hours, during which a combined yield of 100 gallons per minute was obtained.

46. Well ends in water-bearing conglomerate. Pumping plant consists of a single-acting cylinder pump (cylinder with 20-foot suction pipe set 120 feet below surface), a 4-horsepower gasoline engine, and a 1,275-gallon elevated tank.

48. Well ends in water-bearing conglomerate.

50. Dug to 69 feet; drilled to bottom. Penetrated alternating beds of clay and gravel, including four beds of water-bearing gravel. Pumping plant consists of a No. 5 vertical centrifugal pump with a rated capacity of 750 gallons per minute, set 69 feet below surface, and a 30-horsepower crude-oil engine. Drilled portion of well is cased, the upper 10 feet and lower 45 feet being perforated. Said to have been pumped at the rate of 900 gallons per minute for several hours without apparent effect on yield.

IRRIGATION.

Both the yield of wells and the ultimate supply of ground water will no doubt be found to be much less in Paradise Valley than in the Salt River valley, but the prospects for obtaining dependable supplies from underground sources for irrigation on a small scale are sufficiently encouraging to justify the sinking and testing of wells for this purpose.

Irrigation wells should be either dug or drilled to the water level and thence drilled a considerable depth into the zone of saturation in order to tap as large a section of water-bearing beds as practicable. The wells should be cased below the water level, and if drilled from the surface down they should be cased throughout. Double stove-pipe casing not less than 8 or 10 inches in diameter, such as is used at the Phoenix waterworks and at other pumping plants in the Salt River valley, is probably best adapted for irrigation wells in Paradise Valley. At every satisfactory water-bearing bed the casing should be perforated with holes as large as the character of the sediments will permit and as numerous as is mechanically practical. After the casing has been inserted and perforated the well should be pumped long and hard in order to withdraw the fine sediments and to develop around the intake of the well if possible a cylinder of coarse, clean gravel that will yield water freely. Beds of fine sand that require strainers of fine mesh are not of much value for irrigation supplies.

Pumps adapted for lifting water for irrigation in this valley are vertical centrifugal pumps, generally of two or more stages; turbine centrifugal pumps; and deep-well cylinder pumps, preferably double-acting. If an ordinary vertical centrifugal pump is used the hole must be dug at least to the water level and the pump must be installed at or below this level. Two or more wells can be drawn upon with a single pump of this type if they are connected by tunnels at the water level, and suction pipes are extended from the pump, through the tunnels, into the accessory wells. Turbine pumps have the advan-

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all development in hydraulic science. Inductive reasoning based on the fundamental laws of this science, as discovered and enunciated by the ablest scholars, must be supplemented with deductions based on experience and experiment. Olmsted, in the introduction to his textbook on natural philosophy, already cited, was careful to state that "in this part of the doctrine of fluids the deductions of theory alone are of little value and are in fact so discordant with experience that little reliance can be placed on them except as modified by experiment. When thus modified, the truths learned respecting the laws that govern the motions of fluids have a high degree of practical utility."

The deductions from experience and experiment are usually introduced into hydraulic formulas as coefficients or constants. It is practically true that the application of any hydraulic formula involves the determination and use of coefficients or corrections. A coefficient that has been determined under a certain set of conditions may afterward become so associated with the formula that it comes to be regarded as part of a fundamental law. This is true of some of the so-called "standard" weir formulas, which are frequently applied to conditions entirely at variance with those under which the coefficients were determined.

Rational formulas must indeed be based on natural laws, and it is only by the application of inductive reasoning to practical problems that the fundamental natural relations may be determined. It is not always possible, however, to convert the basic natural law into a practicable working formula; the determination of the discharge in an open channel by a process of inductive reasoning would be so complicated as to make the use of such a method absurd. Chezy's suggestion, made in 1775, that the velocity might be expressed as a function of the hydraulic radius and the slope, $V=C\sqrt{RS}$, is the farthest advance science has yet made in that direction. It is an admirable attempt to express in a rational manner the factors that determine the flow in an open channel, and the form of the expression is not questioned to-day so much as the value of the coefficient to be used. Various methods for the determination of C have been proposed, but the results are so uncertain that no well-informed hydraulic engineer would attempt to apply Chezy's formula to the determination of river discharge except where roughly approximate results would be acceptable.

The earlier experimental work in the measurement of flowing water was necessarily based largely on volumetric measurements. This method, while giving the greatest accuracy, is unfortunately limited in its application to problems dealing with comparatively small quantities of water. The experiments on discharge over thin-edge weirs by J. B. Francis in 1851–52 and his expression of the law

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of flow by a rational formula constituted an important step toward standard methods for the measurement of water in motion. Later investigators, notably Fteley and Stearns in 1877 and Bazin 10 years later, suggested various modifications of Francis's formula and also somewhat different coefficients. The investigations of Bazin, especially, were exhaustive and his deductions marvels of mathematical exactness. Even more important, as a means of measuring the flow of natural streams, was the development of the velocity-area method. The possibilities of the wide application of this method were recognized as early as 1889, as was also to some extent the great amount of detail to be systematized and perfected. The ways devised for determining the velocity were many and ingenious. The simplest and probably the first way of estimating the velocity was by means of floats. This method was unsatisfactory, as it was soon discovered not only that a large number of observations were needed throughout the cross section, but also that the velocity of the water as related to the velocity of the float was somewhat indefinite. Various questions arose relating to the observation of velocity, such as the frequency with which these observations should be made across a stream and the best method for determining the mean velocity at a section. These questions could not be decided by abstract reasoning, but had to go through the evolutionary process of experience and experiment. Thus working rules were developed from existing knowledge, and as new facts became established by empiricism they were incorporated into the procedure.

From the demand for a method of determining the flow in an open channel—a method which should be as simple as possible consistent with the desired accuracy and at the same time of the widest application—stream gaging in its present status has been evolved. It is a very recently developed branch of a modern science. The status of hydrometry at the time of the beginning of water-resources investigations by the United States Geological Survey, no longer ago than 1889, is well shown by an extract from the Tenth Annual Report of the Director,[1] as follows.

> The measurement of water flowing in a stream is not an easy matter. It requires skill and rather costly instruments. While the general method has been the subject of much inquiry by a few men and has been practiced to a small extent, there is a wide variation in details and considerable uncertainty or discordance in results. At the beginning of the organization there were no men available who possessed the requisite experience and skill, except two or three men who were occupying responsible positions, and it was doubtful if they could be induced to relinquish them. Neither were any instruments to be found in the market as articles in regular supply, and such as were needed must be made to special order. The investigation of the amount of water available for catchment required the opening up of an entirely new field of research.

[1] Powell, J. W., U. S. Geol. Survey Tenth Ann. Rept., pt. 2, p. 78, 1890.

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As stream gaging is so new an outgrowth of a modern science it must inevitably undergo many changes in the course of its evolution. The lines that will be followed in its future growth can be surmised only from its past history. The improvement of the current meter and its use in the velocity-area method marked a great advance in the science of stream gaging. To judge from the course of development of the meter, further improvements and simplifications of it will doubtless continue to appear from time to time.

Methods for the measurement of discharge—such as the method of using salt or other chemicals, or the relatively recent one of using a diaphragm in open channels of uniform cross section—are likely to become increasingly valuable. But, as with the use of the weir, they probably will not be universally applicable, though they may appreciably cut into the present field of the meter. As a generally applicable means of measurement the current meter is undoubtedly founded on the right principle, and it is hardly conceivable that the meter will be superseded.

A study of the evolution of stream gaging shows the important part played by empirical development together with scientific research, and it is even conceivable that in time the same results might have been obtained through the empirical process alone as through the joint application of theory and experiment. This fact is illustrated by some features of the present method of stream gaging. The observations of velocities at six-tenths of the depth or at two-tenths and eight-tenths of the depth have resulted from a large amount of experiment, but it is now well known that these methods are substantiated by the form of the vertical velocity curve, which is that of the parabola. Had this scientific fact been earlier recognized and applied, it would undoubtedly have materially reduced the amount of research necessary to establish these methods for obtaining the mean velocity. In fact, one criticism which may be made in regard to the development of the present status of stream gaging is that possibly too much reliance has been placed on empirical methods and the advantages to be gained from scientific analysis have been given too little recognition. Although the fundamental principles of stream gaging now seem to be fairly well developed, it should be remembered that before a step can be considered final, it must be confirmed by both theory and experience and that there is no method so well established that it may not be materially modified as a result of future research.

Theoretical considerations embraced under the science of hydraulics constantly appear as supplementary to the practical applications. For example, a thorough knowledge of Chezy's formula, in which the laws of uniform flow are succinctly expressed, may often be of great

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general been similar to those ordinarily followed in stream gaging and based on current-meter determinations of velocity. In some special investigations, however, where comparatively small quantities of water were concerned, volumetric methods were used.

The work of the United States Reclamation Service probably represents fairly well the present status of stream gaging in its practical application to the problems other than those encountered in the collection of statistical data. Determinations of the friction losses in large-sized wood-stave pipe, the varying effect of vegetation on the flow of water in canals, the values of the coefficient of roughness for different materials, the proper coefficient to be used in computing discharge through gates, the rate and amount of seepage losses and the economic possibility of lining canals to prevent such losses, the fluctuations in flow due to increased diurnal seepage and evaporation during the day, the efficiency of pumps and turbines, and the economic size and cost of power plants for pumping water for irrigation are some of the hydraulic problems to which the Reclamation Service engineers have applied the science of stream gaging.

The determination of the actual efficiency curves of power-plant operation is a field for the application of stream gaging at the present time. Various methods have been proposed for the testing of water wheels when installed and under everyday conditions of operation, the use of chemical solutions being advocated by some engineers, but for general application under ordinary conditions the current-meter method gives results more consistent than may be obtained in any other way. As in any application of stream gaging to intensive studies, the method must be used intelligently and by experienced engineers to be successful. The limitations of the meter must be known and precautions taken to insure favorable conditions for field work. Then with ordinary care it will be found that the measurements of water through the wheels are more accurate than the coordinate determinations of the electrical units on the switchboard. A study of power-plant efficiency is illustrated by figure 16, which gives the net efficiency curves for four units of a hydroelectric plant under ordinary working conditions. Units Nos. 1, 2, and 3 are identical in construction and consist of two 36-inch wheels set tandem on horizontal shafts direct-connected to 1,000-kilowatt generators of the General Electric Co. class 20, 1,000 kw., 240 r. p. m. type; the turbines are operated by swing gates. Unit No. 4 is of similar construction except that the generator is of larger capacity, being of the General Electric Co. class 16, 1,200 kw., 300 r. p. m. type, and the wheel gates of piston type. The normal operating head is 50 feet, half of which is derived from draft tubes. These curves were obtained as supplemental data incident to the rating of the power plant for a

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fore expressed may be confidently expected, it should also be remembered that the results of stream gaging have already been applied to the measurement of rainfall on a large scale and to problems involving no less complicated features than the determination of effects of deforestation on the navigability of interstate streams. A large amount of research is yet needed before hydraulics can be considered an exact science, but the recent developments in stream gaging point to the possibility that this branch of hydraulics may in time reach a state of perfection so commensurate with the requirements imposed upon it that all problems connected therewith may be solved with mathematical exactness and the term "probable error" be reduced to a rational quantity. With "accuracy" as the watchword and an "exact" science as the ideal the developments in the science of hydraulics that may be wrought by the means of the current meter and the stop watch should be such as to justify the highest expectation of the most enthusiastic stream gager of to-day.

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GROUND WATER IN BIG SMOKY VALLEY, NEVADA.

By O. E. Meinzer.

INTRODUCTION.

GROUND WATER FOR IRRIGATION IN NEVADA.

The agricultural conquest of vast areas of arable land belonging to the public domain of the United States—the conversion of these apparently boundless expanses of Government land into hundreds of thousands of productive farms and well-provided homes within the last few decades—forms a brilliant chapter in the history of this country. A consideration of this marvelous agricultural development leads at once, however, to a serious problem of the not distant future. Only a few years ago the supply of agricultural land in the great West was commonly assumed to be inexhaustible; to-day the country is beginning to realize that virtually all the tracts which can readily be made productive without irrigation have been occupied and that practically all the streams which can be utilized for irrigation without the installation of expensive storage projects have been appropriated. Moreover, in comparison with the rapid progress in the past, the limits of agricultural development, even with the greatest possible conservation of soil and water and the application of the best cultural methods, appear to be not indefinitely remote. But the realization in recent years of the fact that the part of the public domain which has value for agriculture is rapidly being taken up has itself provided a powerful motive for further acquisition of agricultural land and has induced men and women eager for farms and homes of their own to settle in large numbers in areas where the conditions are so unfavorable or so poorly understood that failure and suffering are inevitable.

In Nevada the bedrock forms a corrugated surface consisting of more or less parallel mountain ranges and broad intervening troughs that are filled to great depths with rock waste washed from the mountains. These great deposits of rock waste were in large part laid down by torrential streams and are relatively coarse and porous. Because they are porous they allow the rain that falls upon them and the run-off that reaches them from the mountains to sink into them, and consequently the desert valleys which they underlie have

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an exceptionally arid aspect. These deposits are, however, great water conservers, for they constitute huge reservoirs in which the supplies received by percolation are stored, and, to the limit of the capacity of the reservoirs, are protected from evaporation. So well are these supplies hidden that their existence was not suspected by many of the early travelers, and even to-day long desert roads without watering places lead over areas where ground water could easily be obtained.

The demand for farm homes is so great and will continue to be so great that strenuous efforts will be made to utilize by irrigation every existing water supply. The ground waters underlying the Nevada deserts will certainly receive more attention in the future than they have in the past, and costly projects for their recovery will be undertaken. Some of these projects will no doubt fail, but others will eventually be successful. So great is the eagerness for land that the report of a single flowing well or the skillful advertisements of a promoter may at any time start a stream of home seekers, ignorant of the actual conditions and difficulties, into almost any of the desert valleys of the West.

It is very desirable that the possibilities of these valleys should be thoroughly investigated before they are invaded by home seekers. The helplessness of the ordinary settler when he confronts the unfamiliar and inherently difficult problems of irrigation with ground waters is illustrated in Big Smoky Valley as well as in other areas. In the south basin of this valley (see fig. 17) there have been a few attempts at irrigation with ground water, but they were made either so far up the slopes that the high lift rendered the cost prohibitive or else in the alkali area where agriculture is not feasible; none apparently have been made in the zone in which the ground-water conditions are the most favorable.

As the ground water is hidden beneath the surface there is necessarily much uncertainty as to its occurrence, and therefore corresponding caution should be observed in regard to ground-water projects. Much can be determined as to the ground waters of desert valleys, however, even where no wells have been sunk, provided the proper observations are made and the proper criteria applied. It is generally possible to ascertain definitely where the ground water is near the surface, to outline the shallow-water areas, and to make an intelligent forecast of the depth to water in other parts of the valley. If sufficient observations are made it is also generally possible to form a rough estimate of the quantity of water that is annually available and to predict to some extent the capacity of wells, the quality of the water, and the cost of recovery. To begin to develop the ground-water supply of a valley without first investigating its ground-water conditions is as unwise as it would be to start to build a railroad

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without first having the route surveyed, and the financial results are likely to be no less disastrous.

Even where a satisfactory supply of ground water is assured irrigation may be impracticable because of the high cost of recovering the water or the unfavorable climatic, soil, or market conditions. The problem of cost must be attacked from two principal directions: (1) Means must be devised for recovering the water at the least possible expense, and (2) crops must be found, methods of irrigation and cultivation devised, and markets developed which will result in the largest possible returns from each unit of water used. In many cases different crops and different methods of irrigation and cultivation will be required with ground-water than with surface-water supplies, and for this reason the ground-water investigations of the Geological Survey should be supplemented by correlative agricultural investigations by the experiment stations.

GEOGRAPHY OF BIG SMOKY VALLEY.

Big Smoky Valley is a typical Nevada desert valley—a plain hemmed in by mountain ranges and underlain by porous rock waste eroded from these ranges and saturated with water discharged from them. Like most of the valleys of the State, it has a general north-south elongation and an interior drainage. The valley itself covers somewhat more than 1,300 square miles (exclusive of Ione Valley), and the entire drainage basin covers 3,250 square miles, has a length of 130 miles, and extends from about the geographic center of the State to a point less than 20 miles from the California line. The valley lies in parts of Lander, Nye, and Esmeralda counties and is crossed by the thirty-eighth and thirty-ninth parallels and the one hundred and seventeenth meridian. (See fig. 17.)

The drainage basin of Big Smoky Valley is divided by a low, gentle, alluvial swell west of Manhattan into a north basin, which contains the upper valley, and a south basin, which contains the lower valley. Each of these basins held a lake in the Pleistocene epoch and each at present contains an alkali flat. Ione Valley, which lies west of Big Smoky Valley proper and has a drainage basin of about 500 square miles, discharges into the lower valley from the northwest and hence forms a part of the south basin. The lowest point in the north basin is 5,443 feet above sea level and the lowest in the south basin is about 4,720 feet. Arc Dome, the culminating point of the inclosing mountain rim, is 11,775 feet above sea level. It is in the Toyabe Range, which forms the west edge of the north basin.

The climate is arid and exhibits the characteristic features of aridity. At a station maintained in the northern part of the valley the average annual precipitation during a period of six years was found to be 6.55 inches. In the southern part the precipitation is still less, and only on a few of the highest mountains is it considerably more.

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tigation was begun, however, flows have been struck in several wells drilled on the west side of the upper valley. These flows and the work of the United States Geological Survey have aroused interest in the subject of utilizing the ground-water supply. A comprehensive report with detailed maps of the valley is in preparation, but in order to meet the immediate need for information as a result of this new interest the present brief paper is published in advance of the complete report.

PHYSIOGRAPHY.

Mountains.—The upper valley is bordered on the west by the Toyabe Range and on the east by the Toquima Range. The lower valley is bordered on the north by the Toyabe and Shoshone ranges, on the east by the Toquima and San Antonio ranges, on the south by Lone Mountain, on the southwest by the Silver Peak Range, and on the west by the Monte Cristo Range.

The Toyabe, which is the largest and loftiest of these ranges, consists of an undulating upland and a steep, rugged front facing the valley. There is evidence that the undulating upland was formed by long-continued erosion in a period when the mountains had less relief than at present, and that the steep front was produced later by faulting and uplift. The very steep front of Lone Mountain is also believed to be a fault scarp.

Altogether about 625 square miles of mountain area is tributary to the upper valley and 1,050 square miles (including 250 square miles in Ione Valley) to the lower valley. The mountains adjacent to the lower valley are, however, lower and more arid than those adjacent to the upper valley and they supply less water.

Alluvial fans.—Most of the surface of Big Smoky Valley consists of alluvial fans built by the streams out of the material washed from the mountains. Small gravelly fans that end abruptly and have little or no arable land are found at the mouths of the small dry canyons, and expanded, gently sloping fans are found at the mouths of the large canyons. The lower parts of the large fans contain extensive areas of excellent soil. The largest areas of good soil in Big Smoky Valley are on the lower parts of the fans of Kington Creek and the Twin Rivers, on the gently sloping surface at the north and south ends of the alkali flat in the upper valley, and on the gently sloping surface that extends northwestward from the alkali flat in the lower valley.

Ancient beaches.—In the Pleistocene epoch Big Smoky Valley contained two large lakes, one of which occupied the lowest parts of the north basin (Pl. VI) and the other the lowest parts of the south basin (Pl. VII). The ancient lake in the north basin may appropriately be called Lake Toyabe, and the one in the south basin Lake Tonopah.

Lake Toyabe at its highest level had a length of about 40 miles, a maximum width of 9 miles, and an area of approximately 225 square

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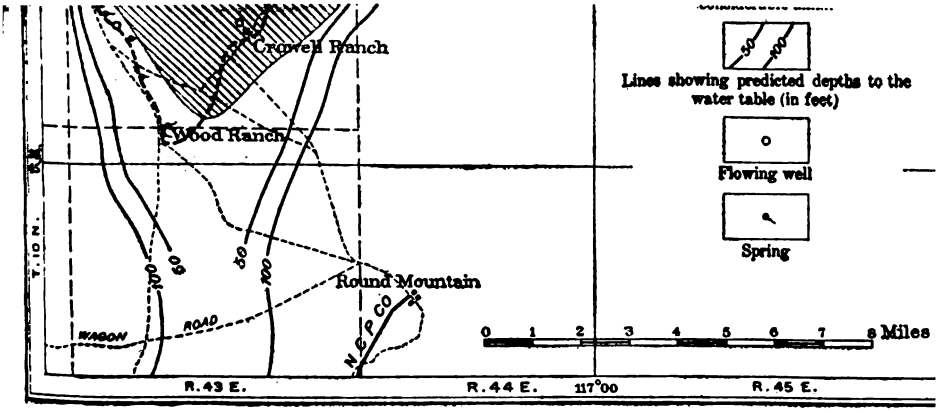

MAP OF THE SHALLOW-WATER AREA OF THE UPPER BIG SMOKY VALLEY, NI

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miles, or 18 per cent of the drainage basin in which it lay. Its maximum depth was about 170 feet, and its shore line, which, so far as was determined, is still horizontal, stood a short distance above the present 5,600-foot contour and measured about 85 miles in length. The maximum depth of the part of this lake that lay south of the ridges southeast of Roger's ranch was only about 70 feet. When the surface of the water went down the lake divided into two parts which were completely separated by an isthmus formed by these ridges.

Lake Tonopah at its highest recognized level had a length of about 22 miles, a maximum width of 5½ miles, and an area of approximately 85 square miles, or only about two-fifths that of Lake Toyabe. This area was only 4.2 per cent of the total drainage basin tributary to the lake—a percentage less than one-fourth as great as that of Lake Toyabe. The maximum depth of Lake Tonopah was about 70 feet, and its highest shore line stood a little below the present 4,800-foot contour, or about 825 feet below that of Lake Toyabe. The total length of the Lake Tonopah shore line is estimated at 53 miles.

The existence of these ancient lakes and the dimensions given in the foregoing paragraphs are deduced from the shore features which were formed by the waves and currents of the lakes and which are still in existence. These shore features consist almost entirely of gravelly beaches and beach ridges, or embankments, many of which are very definite structures that can be followed for a number of miles, the largest attaining heights of nearly 50 feet. In each basin they are found at several different levels, indicating that the surface of both lakes fluctuated. The highest discernible shore features are in positions indicating that neither lake had an outlet, even at its highest level, and it is therefore inferred that the water of both lakes was salty.

Playas.—The principal playas, or alkali flats, in Big Smoky Valley are found in the depressions occupied by the two ancient lakes. The largest extends from the Daniels ranch almost to the Rogers ranch, is nearly 15 miles long, and has a maximum width of fully 6 miles. North of the Daniels ranch a flat, interrupted by beach ridges, extends for many miles, and south of the Rogers ranch another large flat extends toward Wood's ranch. The main playa of the lower valley occupies the depression extending from the vicinity of the French well southwestward to the Silver Peak Railroad.

Fault scarps.—On the alluvial slopes east of the Toyabe Range and north and northwest of Lone Mountain there are numerous escarpments which face the valley and are believed to be due to recent faulting. In some localities there are two or three parallel escarpments with maximum displacement of more than 100 feet. Springs issue from the fault scarps back of Bowman's, Mrs. Gendron's, and McLeod's ranches, and the seepage supports a zone of vegetation that makes the scarps conspicuous as green bands.

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GEOLOGIC FORMATIONS.

PREQUATERNARY ROCKS.

Limestone, quartzite, slate, and schist, aggregating several thousand feet in thickness and ranging in age from Lower Cambrian to Carboniferous,[1] are the oldest rocks found in this region. Since their deposition they have been extensively deformed, eroded, intruded by lavas, and largely covered by igneous bodies and sedimentary deposits. Originally they probably covered the entire region, but at present they are found over extensive areas only in the Toyabe, Toquima, Silver Peak, and Lone Mountain ranges. In the Toyabe Range they lie at the surface over most of the area between Birch Creek and Bowman's ranch.

Several great bodies of granite and associated crystalline rocks occur in this region. Wherever their relations have been determined they are intrusive in the Paleozoic strata and older than the Tertiary eruptive rocks.[1] Granite occurs over a large area north of Birch Creek and crops out extensively from Bowman's ranch to and beyond Wood's ranch. A large granite mass occupies the lofty central part of the Toquima Range, particularly in the region east of Round Mountain. Another large granite mass forms the main part of Lone Mountain, and granite crops out in the ridges farther southwest.

Eruptive formations of Tertiary age, consisting of rhyolite and minor amounts of basalt and rocks of intermediate composition with associated tuffs and breccias, occur over extensive areas in all the ranges bordering Big Smoky Valley.[2] They lie at the surface in all or nearly all the Shoshone Range tributary to Big Smoky Valley, in the southern part of the Toyabe Range and in other localities in this range, in large parts of the Toquima Range from the north to the south end, in much the greater part of the San Antonio and Monte Cristo ranges and the hill country north of the Monte Cristo Range, and in considerable areas in the Silver Peak and Lone Mountain ranges.

Tertiary sedimentary rocks are best developed in the foothill region southwest of Lone Mountain and in the region west and southwest of Blair Junction,[3] but they are widely distributed in the ranges bordering the lower valley and either crop out or lie near the surface over extensive areas in the marginal parts of the lower valley and Ione Valley. In some places there is a sharp structural unconformity between the Tertiary beds and the overlying Quaternary deposits, but

[1] Emmons, S. F., Geology of the Toyabe Range: U. S. Geol. Expl. 40th par., vol. 3, pp. 320-348, 1870.

[2] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, 1903; also Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, 1905.

[3] Turner, H. W., The Esmeralda formation, a fresh-water lake deposit: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 191-226, 1900.

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yield fine sediments and also calcium carbonate, by means of which the deposits become more or less cemented. The granitic rocks form arkosic gravel and quartz sand, but only small amounts of clay. The rhyolite and associated volcanic rocks, which are disintegrated chiefly by changes in temperature and frost, yield arkosic gravel and grit with only small amounts of clay and true sand. The tuffs, which consist largely of minute volcanic fragments that are not firmly cemented, weather readily, producing much fine silt.

The slate and limestone waste predominates on the Kingston fan and adjacent tracts and on the Manhattan fan and adjacent tracts and is abundant on the slope adjoining the northern half of the Toquima Range and most of the slope adjoining the Toyabe Range south of the Kingston fan. It forms only a small part of the waste in the lower valley.

Quartz sand derived from granite predominates in the axial part of the valley between Charnock Springs and Round Mountain, and granitic gravel is abundant on the upper part of the slope in this region. Granitic gravel and sand are also abundant on most of the slope south of Bowman's ranch and occupy almost all of the steep slope adjacent to Lone Mountain.

Grit derived from the Tertiary lavas is abundant and widely distributed. It is supplied in great quantities by the southern part of the Toyabe and Shoshone ranges, the San Antonio Range and the hills north of the Monte Cristo Range.

Fine light-colored silt that contains enough clay to bake hard when dry is a characteristic deposit of the axial parts of Big Smoky Valley and is especially abundant in the lower valley, where most of the tuff, from which it is chiefly derived, is found.

PRECIPITATION.

Careful and continuous observations of precipitation have been made at two places in the drainage basin of Big Smoky Valley in recent years—at Tonopah, where the record is complete since August, 1906, and where the United States Weather Bureau has in recent years maintained a station, and at the Jones ranch, less than 3 miles south of Millett, where observations have been made by Fred. J. Jones since September, 1907.

Average monthly and annual precipitation (in inches) at stations in Big Smoky Valley, Nev.

[From records of United States Weather Bureau.]

	Length of record.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Years.													
Millett.....	6	0.90	0.54	0.51	0.46	0.53	0.24	0.87	0.47	0.80	0.51	0.31	0.41	6.55
Tonopah....	7	.54	.54	.59	.34	.30	.24	.59	.53	.60	.44	.55	.43	5.69

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supply. According to estimates based on stream measurements, ten creeks, including Birch, Santa Fe, Kingston, and Carsley creeks, were in September and October, 1914, contributing to the ground-water supply at the rate of about 7,000 acre-feet a year.

Contributions by floods from dry canyons.—All the canyons occasionally carry water in large amounts, the evidences of which may remain long after the floods have passed. Some of the floods involve large quantities of water and produce impressive results, but they occur so rarely that the average annual flood discharge is likely to be overestimated. In the south basin the floods that head in the mountains no doubt make larger contributions to the ground water than the permanent streams, but in the north basin the flood contributions are of less relative importance.

Contributions by underflow.—Since the canyons were cut they have been partly filled with porous rock waste through which water can percolate freely. Hence not all the water discharged by a canyon flows at the surface; a part flows underground and joins the main body of ground water without coming to view.

The existence of an underflow is demonstrated in many places where, owing to some underground obstruction, the water is compelled to return to the surface, producing swampy areas or sudden increases in the stream flow, as in Willow, Peavine, and Cloverdale canyons and at the mouth of Ione Valley.

Many of the smaller canyons have no permanent underflow, and wells sunk in them would find no water. But even these, if they contain detrital deposits, must at certain times conduct considerable amounts of rain and snow water underground. The underflow is contributed to the main body of ground water with almost no loss, whereas only a part—often a very small part—of surface streams reaches the underground reservoir.

Contributions by precipitation in the valley.—The precipitation of light showers in the valley is absorbed by the capillary pores of the soil and does not make contributions to the underground supply, but the heavier rains produce streams or sheets of water which enters the earth wherever the soil is porous or fissured and which is thus added to the underground supply. If only 5 per cent of the precipitation in the valley areas joins the ground water the contribution from this source amounts to nearly 10,000 acre-feet a year in both the north and the south basin.

GROUND-WATER DISCHARGE.

Processes.—The contributions of water to the underground reservoirs are balanced by losses from these reservoirs. The losses occur chiefly through the return of the ground water to the surface but in small part through percolation out of the basin by way of underground

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passages. The return water reaches the surface by flowing from springs or by rising through the capillary pores of the soil or the roots and stems of plants. It is all eventually disposed of by evaporation. The principal groups of springs and the areas of discharge from soil and vegetation are shown in Plates VI and VII. The principal leakage out of the basin is believed to occur at the west end of the south basin.

Discharge from springs.—The main west-side spring line of the upper valley extends, with a sinuous course due to the different sizes of the alluvial fans, from the Vigus ranch to Wood's ranch, a distance of more than 30 miles, and includes innumerable springs that discharge a part of the copious underground supply received from the Toyabe Range. On the east side of the upper valley there is no spring line comparable to that on the west side, probably because the supply from the Toquima Range is smaller than that from the Toyabe Range, but numerous springs similar to those on the west side are found for a distance of 3 miles in the vicinity of the Charnock ranch, and a group of hot springs is situated on the east side near the north end of the valley. On the alluvial slope between the main west-side spring line and the mountains a few springs flow from fault scarps and were apparently produced by impounding through dislocation of the valley fill.

The lower valley, whose ground-water contributions are smaller and less concentrated than those of the upper valley, has no spring line except such as is formed by a few water holes a short distance west of Millers. At San Antonio and the constricted outlet of Ione Valley springs are produced apparently by barriers that bring the water to the surface.

Discharge from soil and plants.—The areas in which discharge from soil or plants is taking place can be determined by observing (1) the moisture conditions of the soil and the position of the water table, (2) the appearance of soluble salts at the surface and the distribution of these salts in the soil, and (3) the distribution of certain plant species that feed on ground water.

In the areas of discharge the water table is generally within 10 feet of the surface and the ground is moist from the water table practically to the surface. Moreover, the salts that are dissolved in the water and are deposited on evaporation are generally found at or near the surface.

The principal plant indicators of shallow ground water and ground-water discharge in the mountain areas are the birch trees and willows; the principal indicators in the valley are salt grass (*Distichlis spicata*),[1] samphire (*Spirostachys occidentalis*), buffalo-berry bush (Shepherdia), giant reed grass (*Phragmites communis*), and rabbit bush (*Chryso-*

[1] The plant species mentioned above were, with a few exceptions, identified by Dr. P. B. Kennedy, botanist, Nevada Agricultural Experiment Station, but he is not responsible for the field interpretations.

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thamnus graveolens). Certain wild grasses used for hay or pasture also discharge ground water.

The big greasewood (*Sarcobatus vermiculatus*) is abundant in the shallow-water areas and in areas with moderate depths to water, where it no doubt receives a part of its supply from the main body of ground water, but it is not confined to these areas. The iodine weed (*Suæda torreyana*) grows in alkaline soil and is generally found where more than an ordinary supply of moisture is available, but in Big Smoky Valley it appears not to be a reliable indicator of shallow ground water, as it occurs in localities that are far above the water table. The tall shrubby salt bush (*Atriplex torreyi*) is not common in Big Smoky Valley, but grows here and there. It can endure considerable alkali and is generally found in low places with more than an ordinary supply of moisture, but it is not a reliable indicator of shallow water. Common sagebrush (*Artemisia tridentata*) is found chiefly near the bases of the alluvial slopes and along stream courses, where there are better supplies of moisture from flood waters than on the higher parts of the slopes and where the soil does not contain excessive amounts of alkali. It occupies some of the land that is most promising for agriculture. So far as known, sagebrush does not utilize water derived from the zone of saturation. It is not an indicator of shallow ground water.

The spiny salt bush (*Atriplex confertifolia*), often called shadscale, and the little, dry species of greasewood (*Sarcobatus baileyi*) are commonly associated and are the dominant plants on the dry slopes and plains that lie far above the water table. White sage, or winter fat (*Eurotia lanata*), also grows on the upland plains far above the water table.

The interior of large playas, such as the Millett and McLeans flats, are entirely barren over extensive areas. Barrenness is, however, not an indication of ground-water discharge, for it is as characteristic of some of the flats having considerable depths to water as of those having shallow water.

The largest area of ground-water discharge is in the interior of the upper valley. (See Pl. VI.) It extends a distance of 40 miles, attains a maximum width of more than 8 miles, and covers about 160 square miles, or 100,000 acres. Its northern extremity is only a few miles south of the Spencer Hot Springs and its southern extremity is in the vicinity of Wood's ranch. In all of this area the process of ground-water evaporation is uninterrupted except where the large beach ridges cross the axis of the valley. The northern and southern limits of the area are somewhat indefinite, owing to the very gradual increase in the depth to water along the axis of the valley.

The principal area of ground-water discharge in the lower valley extends from a point about 2½ miles southwest of Millers to a line

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WATER LEVELS.

Over an area of 160 square miles in the upper valley and an area of 45 square miles in the lower valley the water table, or upper surface of the main body of ground water, is generally within 10 feet of the surface of the ground. These shallow-water areas practically coincide with the areas of ground-water discharge, already referred to (p. 98), and are shown on Plates VI and VII. The outlines of these shallow-water areas were determined partly by examining wells and boring holes to the water table, but more largely by interpreting surface indications of shallow water afforded by the moisture in the soil, the soluble salts at the surface, and certain species of native plants (pp. 97, 98).

On all sides of each of the shallow-water areas, with possibly some local exceptions, the water table rises gradually in the direction of the mountains. In some places on the west side of the large flats in the upper valley it rises at about the same angle as the surface of the ground, and hence is within 10 feet of the surface at points more than 100 feet above the flats. In general, however, the slope of the water table is much less than that of the land surface. The lines on Plates VI and VII, showing depths to water of 50 and 100 feet, respectively, are based on determinations, from the topographic map and by the use of the hand level, of the slope of the land surface, and on reasonable assumptions as to the slope of the water table. In the lower valley there are several comparatively deep wells that give some control of the 50 and 100 foot lines, but in the upper valley there are no wells in which the water level is more than 20 feet below the surface. Although the lines showing depth to water are only forecasts and will, without doubt, be found to be considerably in error in some localities, they are believed nevertheless to be of value in directing developments.

According to the data and forecasts shown on Plates VI and VII, the areas with specified depths to water are as shown in the following table:

Estimated areas having specified depths to water table in Big Smoky Valley, Nev.

Depth to water table, in feet.	North basin (upper valley).	South basin (lower valley).	Total.
Total areas:	*Acres.*	*Acres.*	*Acres.*
Less than 10 (alkali land)	100,000	30,000	130,000
Less than 50	170,000	70,000	240,000
Less than 100	215,000	120,000	335,000
Areas exclusive of alkali land:			
Less than 50	70,000	40,000	110,000
Less than 100	115,000	90,000	205,000
Areas exclusive of alkali, gravelly, and sandy land:			
Less than 50	45,000	20,000	65,000

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probably not be obtained. There is a possibility of obtaining supplies by drilling into the Tertiary strata, but the prospect is too poor to make deep drilling advisable, at least until the more promising supplies from the Quaternary fill in other parts of the valley have been developed.

ARTESIAN CONDITIONS.

In the last two years seven flowing wells have been sunk in the upper valley and drilling was in progress when the valley was last visited. These wells are all in or very near the area of ground-water discharge, which has more or less alkaline soil and a depth to water not generally exceeding 10 feet (Pl. VI). The most successful one is the 127-foot well of Fred. Jones (Pl. VI), which is 6 inches in diameter and is finished with standard casing without perforations, the water entering through the open end at the bottom of the well. The first flow was struck at a depth of 68 feet, and a stronger flow was struck at 117 feet in a 10-foot bed of gravel below a layer of dense clay. The flow when measured on October 7, 1914, was 120 gallons a minute. The cost was $221, including the casing. As shown in the table on page 114, the other wells have depths ranging from 40 to 133 feet and yields ranging from 10 to 40 gallons a minute.

The prospects of obtaining flowing wells are, as a rule, best where the water table is nearest the surface, and no money should be spent in drilling for flows outside of the 50-foot boundaries shown on Plates VI and VII. The most favorable conditions are found in the shallow-water area on the west side of the upper valley, where the slope from the mountains is steep and the water supply is abundant, but there are also prospects on the east side between the Charnock springs and Wood's ranch. To a large extent the flowing-well area will be found to be in the areas of alkali soil, but it may be possible to get satisfactory flows on some good land just outside of the alkali areas, especially at the bases of the alluvial fans of Kingston Creek, Twin Rivers, and Jefferson Creek. Even where the soil contains considerable alkali flowing wells will be profitable provided there is enough slope to make the removal of the alkali practicable, as is the case near the west edge of the alkali area in the upper valley, and provided the yield of the wells is large enough to make the cost per acre comparatively small, as is the case with the Jones well.

The conditions for obtaining flowing wells in the lower valley are believed to be less favorable than in the upper valley because the fill is not so deep, the contributions to the ground-water supply are smaller, and the principal sources of supply are farther from the shallow-water area. If any drilling for flowing wells is undertaken in the lower valley it should be done a short distance west of Millers, where the soil is fairly good but the water table is not much more than 10 feet below the surface.

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for drilling flowing wells in fine valley fill and they are well adapted for similar use in Big Smoky Valley. The wells drilled with these outfits are generally small, but there appears to be no reason why they could not be used successfully for holes 6 inches in diameter, which is the smallest diameter recommended for wells to be used for irrigation. The ascending muddy water plasters the walls of the well, producing a remarkably effective mud casing. Even in a deep well in soft material it is generally not necessary to insert casing until the entire hole has been drilled. This plastering or puddling process makes the hydraulic rigs the most successful for penetrating quicksand, but it involves the danger of shutting out valuable water-bearing beds.

The most serious difficulty that has been met in drilling in Big Smoky Valley is produced by beds of quicksand, which are always hard to handle. If the bed of sand is not too thick it may be possible to drive the casing through it into a firmer formation, or if the sand does not run too freely it may be possible to bail out enough so that the casing can be driven down little by little. Entrance of sand into the well can to some extent be prevented by keeping the well as full of water as possible, thereby producing a back pressure. Other methods of penetrating quicksand consist of (1) freezing the formation, which is too expensive for ordinary water wells, (2) inserting cement, which sinks into the quicksand and sets, after which it can be drilled through, and (3) puddling with mud by the hydraulic process. The puddling method is the most practicable for use in Big Smoky Valley.

For pump wells of large diameter double stovepipe casing, about No. 12 gage, such as is widely used in California, is probably the most economical casing that is adequate. It is commonly used in wells sunk with mud scows, where it is inserted as fast as the hole is made. In flowing wells it is advisable to use the somewhat more expensive standard screw casing. Wells in the valley fill should not be left uncased. In pump wells the casing should be perforated at every satisfactory water-bearing bed, either before or after it is inserted. Flowing wells, in order to yield the largest amounts possible, should be sunk through the entire bed that furnishes the artesian water and should have their casings perforated where they pass through this bed. Generally there are several satisfactory artesian beds below the one in which the first flow is struck, and in order to get strong flows all of them should be penetrated and the artesian water admitted by perforating the casing. Perforations may be circular holes one-fourth to one-half inch in diameter or vertical slits one-fourth to one-half inch wide.

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QUALITY OF WATER.

Analyses were made by Dr. S. C. Dinsmore of the waters from nearly all the wells, from a number of springs and streams, and from a few test borings; also of the alkali in a number of typical soil samples. All these analyses will be published in the final report. They indicate that the waters in the upper valley, with few exceptions, contain only small amounts of mineral matter and are of good quality for irrigation; that the waters of that part of the lower valley northeast of the area of alkali soil (Pl. VII) contain larger amounts of mineral matter but are also in general good enough for irrigation, and that the waters of the southwestern part of the lower valley contain large amounts of mineral matter and are in general of poor quality or entirely unfit for irrigation.

Of the 18 samples of spring and well waters from the upper valley analyzed, seven contained less than 200 parts per million of total dissolved solids and only two contained more than 500 parts per million. The dissolved solids consist chiefly of calcium and the bicarbonate radicle. The soil analyses show that the two most injurious salts in the soil of the alkali area in the upper valley are sodium chloride and sodium carbonate, the chloride being the more abundant but the carbonate the more injurious. Within the alkali area, as shown on the map (Pl. VI), difficulty with these two salts may be expected, but not all the land within the area is irreclaimable. Indeed, a large part of the land now under irrigation with stream and spring waters lies in the alkali area and has been made fairly productive by persistent and intelligent effort. Except where the soil is already alkaline no serious alkali problem will be developed by irrigating with ground water in the upper valley.

Although the waters from the northeastern part of the lower valley (that is, the part northeast of the area of alkali soil) contain somewhat larger amounts of total dissolved solids than the ground waters of the upper valley they do not generally contain as much as 500 parts per million. They have slightly less calcium than the waters of the upper valley but considerably more sodium and somewhat more chlorine and sulphate. The quantities of all the sodium salts in the waters of the northeast province are, however, so moderate that these waters are believed to be generally satisfactory for irrigation except where the soil already contains injurious amounts of alkali. The boundary of the area of alkali soil is shown in Plate VII, but on the northeast the limits are not definite and some alkali may be encountered beyond the boundary shown on the map. Reclamation of the land in the alkali area is not believed to be practicable, the drainage being much poorer than that of the reclaimed alkali land in the upper valley.

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IRRIGATION.

DEVELOPMENTS.

The acreage of irrigated land in the basin of Big Smoky Valley is difficult to estimate because many of the irrigated fields merge with partly irrigated or nonirrigated meadows, and these in turn merge with unproductive marsh or desert. According to estimates based on the measured or reported dimensions of fields at each ranch, the total area regularly irrigated in the basin is about 2,500 acres, of which about one-half is in alfalfa and one-half in wild grass, the acreage of all other crops being very small. In addition there is about 5,000 acres of meadow land that is occasionally flooded or naturally subirrigated and that ranges from fairly productive grass land to nearly worthless salt-grass marsh. Practically all the irrigated land is in the north basin except about 300 acres along Peavine and Cloverdale Creeks.

Most of the water used in irrigation is obtained from the numerous small mountain streams, but a part comes from valley springs along the western spring line and at the Charnock ranch. Less than 5 acres was irrigated with water from wells in 1913 and 1914. Most of the stream water is used on land near the mouths of the canyons or in open places within the canyons, but a part is led in ditches down the fan slopes and is used in the alkali area (Pl. VI) or on intermediate tracts. The meadow land and nearly all the land irrigated from springs lie within the alkali area, but the alkali has been largely removed from the best fields in this area. The tracts of good soil adjacent to the alkali area generally lie above the springs, but they could be more largely utilized than they are at present for irrigation with stream waters.

There is great loss of stream water by seepage into the porous sediments underlying the upper parts of the fan slopes. Where the water is used on the porous soil near the canyons the loss occurs largely by seepage after it has been applied to the land; where it is used on the tighter soil at lower levels the loss occurs chiefly by seepage from the ditches that lead from the mouths of the canyons to the irrigated fields several miles distant. The arroyos leading from the canyons generally have very porous soil, and to some extent loss has been avoided by using the water on the uplands adjacent to the arroyos instead of using it on the floors of the arroyos themselves, or by leading it through ditches on the upland rather than taking it down the natural streamways. Only a part of the loss, is, however, prevented by these means. The only effective methods of conserving the water supply would be (1) to prevent excessive seepage by constructing water-tight ditches from the canyons to the tracts of satis-

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on account of mutual interference, aggregate considerably less than 500 gallons a minute. In some parts of the valley yields of several hundred gallons a minute can no doubt be obtained from a single properly constructed well.

The cost of pumping water depends largely on the efficiency of the pump and other machinery, and the efficiency depends on numerous mechanical details. These are better understood by the mechanic than by the farmer, but they must be mastered by every farmer who hopes to make a success of pumping for irrigation. They are subjects of general application which can not be adequately discussed in this paper, but are admirably treated in a booklet by Charles A. Norcross.[1] Most of the manufacturing firms have in their service engineers or expert mechanics who will assist farmers in planning installations suited to their particular needs.

POWER.

The cost of the power is usually the largest single item in the cost of pumped well water. With a given efficiency the amount of power necessary to pump an acre-foot of water is directly proportional to the height to which the water is lifted. When the pump is operated the water surface in the well is drawn down from its normal level to some lower level, where it usually remains approximately stationary while the pump is running, but when the pump is stopped the water in the well returns about to its normal level. The total lift is the distance from the water level while the pump is in operation to the level of the outlet of the discharge pipe; that is, it is the depth to the water table plus the drawdown. If the depth to the water table is 25 feet and the drawdown with a certain rate of pumping is 15 feet, the total lift is 40 feet.

Possible sources of power that may be considered for irrigation pumping in Big Smoky Valley are (1) distillate used in small internal-combustion engines installed at the individual pumping plants, (2) electric current from commercial power lines, (3) electric current produced by a central power plant using crude oil or other fuel shipped into the valley, (4) electric current produced by a power plant at the coal mines near Blair Junction, and (5) electric current produced from local water power.

The most practical source of power during the experimental stage of pumping is the gasoline engine using distillate for fuel. The installation should be approximately as shown in figure 18. A shelter should be made for the engine and well and they should be protected from floods.

The approximate cost of fuel if distillate is used is shown in the following table adapted from the bulletin by Norcross:[2]

[1] Irrigation pumping in Nevada: Nevada Bur. Ind., Agr., and Irr. Bull. 8, 1913. [2] Idem, p. 37.

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The line of the Nevada-California Power Co. crosses the area having less than 50 feet to water in the lower valley (Pl. VII) and runs to Round Mountain, which is less than 5 miles from the similar area in the upper valley (Pl. VI), but an extension of many miles would be required to bring the current to the northern part of the shallow-water area of the upper valley. If satisfactory water supplies are developed in the vicinity of Millers and at the south end of the shallow-water area of the upper valley, pumping with electricity could first be tried in these two localities, and if the experiment proved successful the transmission line could later be extended.

Crude oil is delivered at Millers in carload lots for about 4 cents a gallon. A well-equipped central plant using this fuel and connected by electric lines with pumping units could no doubt supply power at less cost than the small gasoline engines installed at the pumping units. Power could probably also be developed at relatively low cost if a plant were built at the Coaldale coal deposits, a few miles southwest of Blair Junction. These deposits have been described by J. H. Hance,[1] of the United States Geological Survey, who makes the following statement:

> The analyses show that the coal has a high heat value and is bituminous, but this desirable feature is partly offset by a high percentage of ash-making constituents. The coal keeps well, slakes very little, and may meet an economical and efficient use in the gas producer. By using it as a gas coal, a power plant might be established at the mines and the neighboring towns and camps supplied with electric power more cheaply than under present conditions. However, it probably will not bear transportation charges, such as prevail in this State, and can scarcely hope to have extensive use as a domestic fuel.

No power plant should, however, be constructed until irrigation with ground water has passed beyond the experimental stage and a supply large enough to justify the necessary expenditure has been developed.

The streams that discharge into the upper valley have steep slopes and great head, but the quantities of water they carry are small, especially in the later part of the summer. The cost of developing water power from these streams for pumping would probably be prohibitive, but the matter is worthy of investigation. According to current-meter measurements made October 1, 1914, Kingston Creek flowed 6.68 and 7.21 second-feet at two points 3½ miles apart and having a difference of elevation estimated at not less than 800 feet. During most of the irrigation season the flow is no doubt considerably greater. With an over-all efficiency of 33⅓ per cent, the power from 7½ second-feet of water falling 800 feet would lift 50 second-feet of well water from a depth of 40 feet. At $3,000 per second-foot the value of this amount of water would be $150,000.

[1] The Coaldale coal field, Esmeralda County, Nev.: U. S. Geol. Survey Bull. 531, p. 322, 1913.

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It is obvious that at present pumping for irrigation is economically practicable only for raising high-priced crops and for raising ordinary crops in localities with exceptionally favorable conditions. The principal favorable conditions referred to are (1) soil that is not injuriously alkaline, sandy, or gravelly, (2) small depths to the water table (not much more than 10 feet), and (3) water-bearing beds at moderate depths that will yield freely.

In the following table are given the estimated costs of the water thus far developed from flowing wells, the cost of drilling and casing being calculated at the same rate as in the Jones wells (p. 102) although the actual cost for some of the wells was greater:

Estimated cost of irrigation water developed from flowing wells in Big Smoky Valley.

Owner.	Depth of well.	Cost of well.	Yield.			Cost.	
			Gallons per minute.	Second-foot.	Acre-feet per season of 150 days.	Per second-foot.	Per acre-foot, interest at 7 per cent and depreciation at 10 per cent.
	Feet.						
Fred. Jones	127	$221.10	120	0.267	79.4	$825	$0.47
Do	68	112.20	30	.067	19.8	1,675	.96
A. B. Millett	101	167.00	40	.089	26.5	1,870	1.07
Ed. Turner	90	148.50	30	.067	19.8	3,200	1.84
Do	40	66.00					
Frank Gendron	?133	?219.45	?10	?.022	?6.6	?9,975	?5.65

The depreciation will be found to vary greatly in both pumping plants and flowing wells, and the estimate of 10 per cent a year for this item is quite arbitrary. The depreciation will probably be as great in flowing wells as in pumping plants, but it will involve different factors. It will not include the wear and tear of pumps and engines, but it will include the gradual diminution in yield that characterizes the history of many flowing wells, especially where there is much development.

The above table shows that in the areas where flows of any consequence can be obtained the cost of artesian water is much less than the cost of pumped water. Flowing wells can profitably be sunk to procure water for irrigation in all such areas even though the soil may contain undesirable amounts of alkali, as is generally the case where flows are obtained. However, the satisfactory flowing-well areas will no doubt be found to be small and easily overdeveloped, and the reclamation of any considerable amount of land will probably be possible only by pumping.

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6. In the areas in which the depth to the water table ranges between 10 and 50 feet there is enough good soil to utilize all the ground-water supply. These areas, however, also contain considerable gravelly, sandy, and alkaline soil.

7. There are some prospects of obtaining flowing wells wherever the water table is near the surface, but the prospects are best on the west side of the upper valley.

8. The flowing-well areas will be found to lie chiefly within the areas of alkali soil, but they may extend into adjacent areas of good soil.

9. Full development of the ground-water supply for irrigation will not be economically practicable until cheaper power or more valuable crops can be introduced than are now in sight.

10. Developments believed to be practicable at present are (1) the sinking of flowing wells of moderate depths in the restricted areas where fairly copious flows can be obtained and the soil is not irreclaimably alkaline, and (2) the sinking of nonflowing wells and the installation of pumping plants for raising high-priced crops and for raising ordinary crops in localities where the conditions are exceptionally favorable or where the well water can be used to supplement surface-water supplies.

11. The raising of high-priced crops is practicable to only a small extent. Vegetables and small fruits could, it is believed, be profitably raised in the vicinity of Millers to supply Tonopah, Goldfield, and other local markets.

12. The principal favorable conditions that are necessary in order to make pumping profitable for raising ordinary crops, such as alfalfa, are soil that is not injuriously alkaline, sandy, or gravelly; small depths to the water table (not much more than 10 feet); and water-bearing beds at moderate depths that will yield freely.

13. Ground-water developments along some of the lines indicated could well be made by the ranchers now in the valley, who could afford to take some chances and who could advantageously use the well water to supplement their fluctuating surface-water supplies.

14. A small number of new settlers could probably make a livelihood by irrigating with ground water in Big Smoky Valley, provided they had a few thousand dollars each to make the necessary developments and used good judgment as to locations.

15. Existing conditions do not warrant the influx of a large number of settlers nor of any without means to sink wells and make other necessary improvements. Ill-advised immigration will inevitably lead to disappointment and suffering.

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Passing to limits, we have

$$dS = \frac{\frac{dh}{dt}}{V + dV}$$

that is, the increase in slope equals the rate of change of stage divided by the velocity, the same as before.

As at the given stage of E′ the area is constant, the formula may be written

$$\frac{Q_1}{Q_2} = \frac{\sqrt{S_1}}{\sqrt{S_1 + \frac{\text{rate of change of stage}}{\text{velocity}}}}$$

Now, the question arises, what velocity should be used? Let A and B, in figure 21, represent two points a short distance apart in a channel. The water at A is traveling at the different rates X_1, X_2, etc., depending on the depth, as indicated by the curve. The surface water is arriving at B at the velocity X_1. Now, suppose more water is turned in at A, raising the stage and the head. Both the mean and surface velocities are increased to carry away this excess. Then that part of the increased flow which travels at the rate of the surface velocity—that is, approximately the upper third of the stream—will arrive at B at the rate of the surface velocity. As fast as this increased flow reaches B, it increases the head by raising the stage and increases R by increasing the cross section. Thus the mean velocity at B is increased, not at the rate of the slow-moving mean velocity at A, but more nearly at the rate of the surface velocity. For this reason it is assumed that the flood travels very nearly at the rate of the surface velocity.

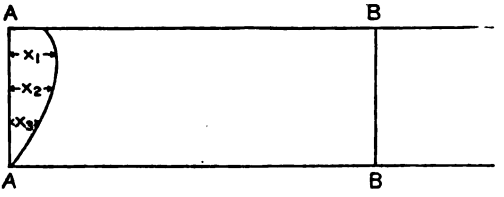

FIGURE 21.—Theoretical vertical velocity curve.

The relation of surface velocity to mean velocity will be the same in this case as under conditions of constant stage, for the mean velocity used is the actual mean velocity measured during the rise. This velocity is automatically governed by the slope, which in turn is governed by the velocity of the flood. If the rise or fall is fairly uniform, the change in slope is fairly uniform, and the relation of mean velocity to surface velocity under such conditions should be exactly the same as if the slope were governed by some other cause. Therefore, to obtain the velocity of the flood—that is, the surface velocity—the mean velocity of the measurement should be divided by 0.9 for large

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streams and by 0.85 for smaller ones. The formula then finally becomes

$$\frac{Q_1}{Q_2} = \frac{\sqrt{S_1}}{\sqrt{S_1 + \frac{\text{rate of change of stage}}{\text{surface velocity.}}}}$$

If K stands for the change of stage per second, V for the mean velocity of the measurement made during the changing stage, and N for the coefficient for obtaining mean velocity from surface velocity, the formula may be written

$$\frac{Q_1}{Q_2} = \frac{\sqrt{S_1}}{\sqrt{S_1 + \frac{\frac{K}{V}}{N}}} = \frac{\sqrt{S_1}}{\sqrt{S_1 + \frac{NK}{V}}}$$

The main difficulty to be met in the field observations is in obtaining the slope accurately. Although the slope at a station usually varies with the gage height, even under conditions of constant stage, still at any given gage height under normal conditions the slope is practically permanent. This is especially true of medium and high stages, at which rapid changes of stage are most likely to occur. By making careful observations at different gage heights, being sure to allow for changing stage, and plotting these observations the engineer can obtain a fairly accurate slope curve for each station.

Any error in S_1 enters into both numerator and denominator. Suppose S_1 were really 0.04 and S_2 were 0.05, but that S_1 were determined as 0.05, which would make S_2 0.06. Here is an error of 25 per cent. But the factor $\frac{Q_1}{Q_2}$ is 0.895 in the first case and 0.913 in the second, an error of about 17 per cent in the correction and of only 2 per cent in the total discharge.

It is obviously necessary that the change of stage and mean velocity must be observed at the same section. If the permanent gage is not at the measuring section, it will be necessary to install a temporary gage to use during the measurement; or, if the cross section at the gage is available, the mean and surface velocity at the gage can be obtained by dividing the discharge from the measurement by the area at the gage.

During the summer of 1914 some experiments were made to test the method, and tables and curves have been prepared giving the results of these tests.

The first experiments were made on Agency ditch, on the Fort Belknap Indian Reservation, near Harlem, Mont. This canal has a capacity of 100 second-feet, but only about half of this flow could be obtained. For a gage, a 2 by 4 inch post graduated to tenths was

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a riffle, and the water at the gage is considerably deeper than on the riffle. The slope and velocity at the gage are therefore very small at low stages, and as the stream rises both increase rapidly at first and then become nearly constant. The slope was determined in the manner described above at five different gage heights, allowance being made for changing stage. A slope curve was drawn to average these five points as shown, and the slope taken from it. The results are not large enough to show up well on a small scale, but Table 2 and figure 23 together give a very good idea of the results. Particular attention is called to measurements 14 and 16, also to 9 and 20.

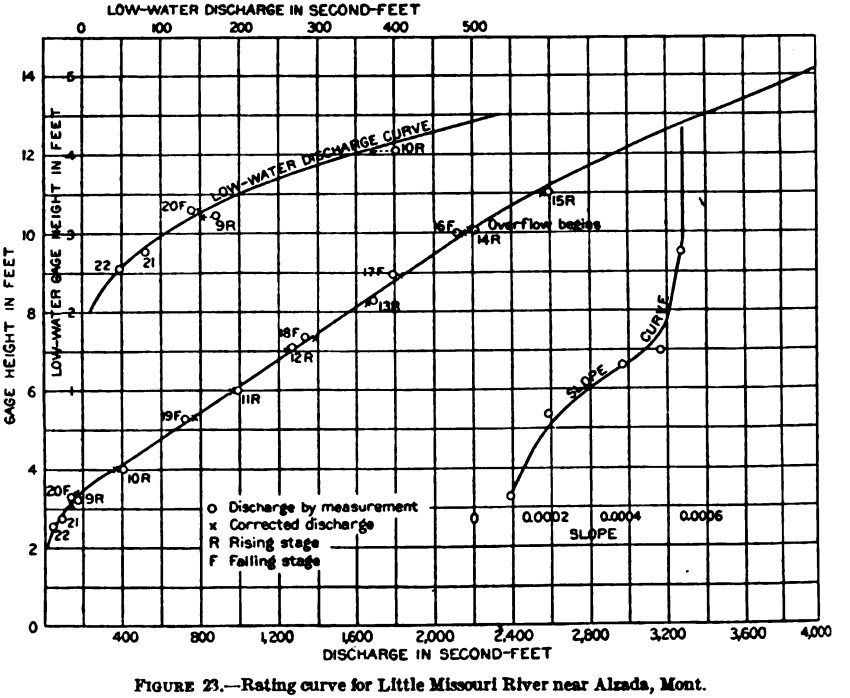

FIGURE 23.—Rating curve for Little Missouri River near Alzada, Mont.

These measurements were made at nearly the same gage height, 9 and 14 being on a rising stage and 16 and 20 on a falling stage. The rate of change for 14 and 16 is much greater than for 9 and 20, but on account of the increased slope and high velocity the percentage of error in 14 and 16 is small. On the other hand, although for 9 and 20 the change of stage is slight, on account of the small slope and low velocity the percentage of error is high. The method takes care of these two extreme cases fairly well, and, although the corrected discharges for 9 and 20 do not agree exactly, they are nearly as good as the average measurement with a constant stage. The error is probably due to errors in obtaining the slope, which is very slight

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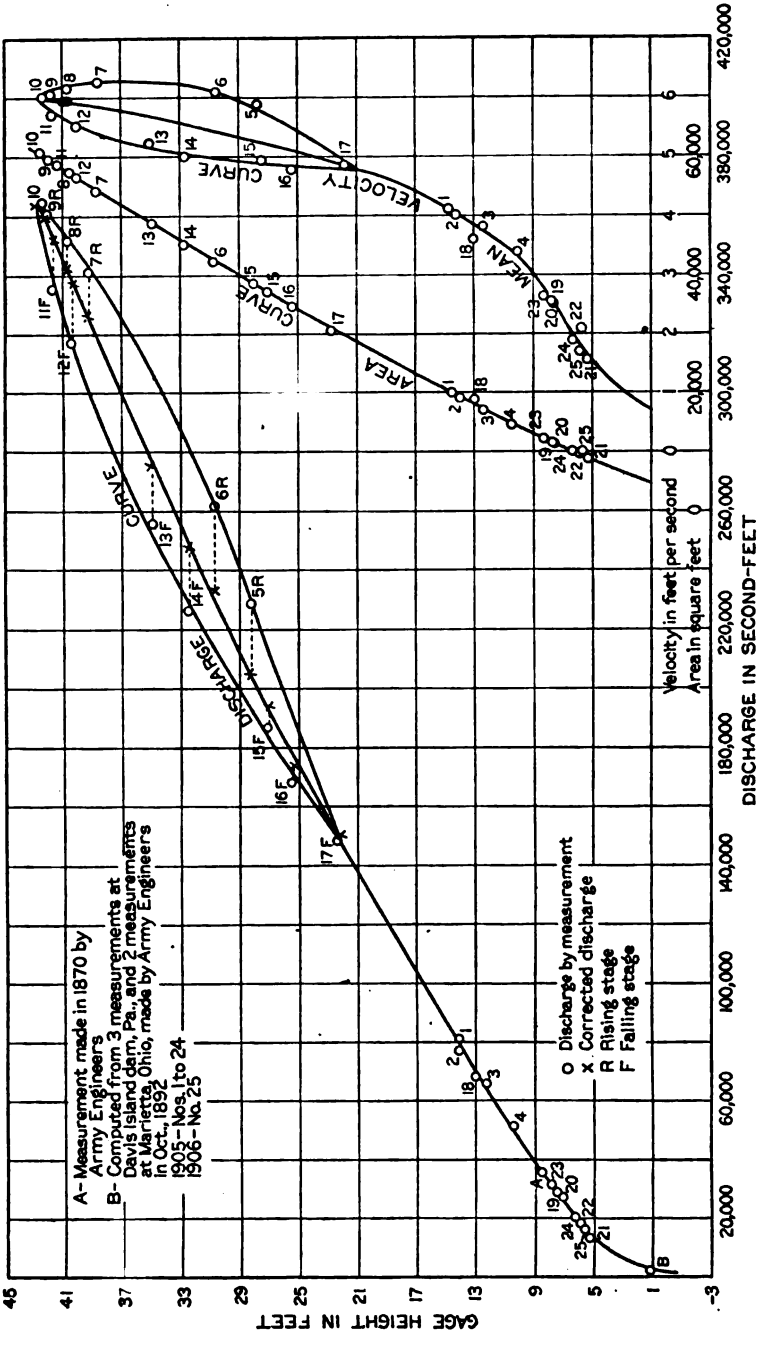

FIGURE 24.—Discharge, area, and mean-velocity curves for Ohio River at Wheeling, W. Va., with measurements at changing stage plotted to both measured and corrected discharge. From Hoyt and Grover's "River discharge."

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$$\frac{205,000}{38,890} = 5.27 = \text{mean velocity at constant stage} = V.$$

$$Q_1 = 205,000$$
$$S_1 = 0.0001135$$
$$K = +\frac{0.68}{3,600} = +0.000189$$
$$N = 0.90$$

By the formula

$$\frac{Q_1}{Q_2} = \frac{\sqrt{S_1}}{\sqrt{S_1 + \frac{NK}{V}}}$$

$$\frac{205,000}{Q_2} = \frac{\sqrt{0.0001135}}{\sqrt{0.0001135 + \frac{0.000189 \times 0.9}{5.27}}}$$

$$Q_2 = 232,000$$

Dividing again by 38,890 to obtain a second approximate mean velocity and proceeding as before gives a second approximation of 229,000 second-feet as the discharge at this gage height and rate of change of stage.

$$\frac{232,000}{38,890} = 5.97 = V$$
$$Q_1 = 205,000$$
$$S_1 = 0.0001135$$
$$K = 0.000189$$

Substituting in the formula, we have

$$\frac{205,000}{Q_2} = \frac{\sqrt{0.0001135}}{\sqrt{0.0001135 + \frac{0.000189 \times 0.9}{5.97}}}$$

$$Q_2 = 229,000$$

The current-meter measurement showed a discharge of 229,200 second-feet.

If many discharges are to be corrected, a table can be prepared giving corrections for different rates of change at different stages.

In the tables all the data are given. In Table 1 in the column headed "Discharge by rating curve" is given the discharge by the constant-stage rating curve for the mean gage height of the measurement. The rating curve is based on measurements 1, 2, 4, and 5,

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applied at the gage without considering and allowing for conditions below the gage.

All the computations given have been made on a slide rule.

Acknowledgments are due to Mr. C. R. Hauke, assistant engineer for the United States Indian Office, for the use of Agency ditch in making the experiments and for furnishing a man to assist in raising and lowering the head gates; also to Messrs. R. R. Randell, W. A. Lamb, and A. H. Horton for assistance, suggestions, and criticisms, and to Mr. C. H. Pierce for reading and criticising the finished paper.

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NOTE.—The foregoing paper was read at a conference of the engineers connected with the water-resources branch of the Geological Survey held in Washington December 12 to 19, 1914, and was discussed as follows:

Mr. Johnson said that on a stream where the gage is a short distance above rapids and where the water has a high velocity a change in stage does not affect the plotting of the measurement. He cited localities in the St. Lawrence River basin to illustrate the point.

Mr. Lamb said that at the localities mentioned by Mr. Johnson the slope and velocity were necessarily high because the gages were above rapids, and that a given change in stage would consequently make a small percentage of change in the slope and would therefore make the coefficient derived from the formula approach unity; on the other hand, if the slope were small and the velocity low, the same rate of change in stage would make a greater change in slope and also a greater change in the ratio of the normal slope to the slope during a changing stage, which would result in a lower coefficient for rising stages and a higher coefficient for falling stages derived from the formula. He said also that the principles involved in the formula are applicable for all slopes, velocities, and rates of change in stage, but that the practical application is confined largely to streams of medium and low velocities.

Mr. Lamb said that where the rise or fall of a stream continued over one or more days an appreciable error would be introduced in the daily discharges if corrections for the changing stages were not applied.

In this connection the following extract from an article by Sir William Willcocks, published in the Engineering Record of July 4, 1914, page 19, commenting on the report of the Pittsburgh Flood Commission, was read:

"CAPACITY OF RESERVOIRS.

"Still, in an important city like Pittsburgh, in addition to whatever you do, something in the way of reservoirs ought to be done if it can be done. In a recent book which you have written on this reservoir question I see that the quantity of water you consider necessary to impound in these reservoirs seems to be in excess of what you need. In all the calculations it has been assumed that when the river rises its discharge increases up to its maximum gage. As a matter of fact, it does just the opposite. When it is rising fast it has a great velocity and a great discharge, but when it comes to within 7 or 8 feet of the top the velocity has begun to decrease and with it the discharge. On the Tigris, which jumps up and down very much like this, when the river gage is 15 feet rising, the discharge is 180,000 second-feet. When it has risen to 20 feet and reached its maximum for that rise, its discharge is 120,000, and when it has come down on the other side to 15 feet the discharge is 90,000 second-feet. As in all these estimates you have allowed for an increasing discharge and not reduced by half for the falling gage, a much smaller quantity of water than you have assumed would suffice to shelter you from these hours of high flood which produce all the worry."

It was stated that, while the conclusions reached by Sir William Willcocks in this particular case might be questioned, they emphasize the fact that a changing stage does affect the discharge, and that the errors introduced may be much greater than the errors introduced in computing daily discharge by applying the mean gage height to the rating table rather than by taking the average of the hourly discharges, also much greater than the error due to diurnal fluctuation.

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CONDITIONS REQUIRING THE USE OF AUTOMATIC GAGES IN OBTAINING RECORDS OF STREAM FLOW.[1]

By C. H. Pierce.

The summary of field operations of the division of surface waters of the United States Geological Survey for 1913–14 contains a statement showing the number of gaging stations maintained by the Survey and the types of gages used. The total number of stations so maintained was 1,741, of which 325 stations were reported as equipped with automatic gages.

The necessity for automatic gages has long been recognized, but probably the first systematic study by which the errors incident to the method of using two gage heights a day could be determined and compared with the errors due to incorrect methods of handling the automatic-gage records was started by the engineers of the Geological Survey in December, 1912. This study was carried on during the year 1913, and comparisons of methods were made for a number of gaging stations in different parts of the United States. One of the results of the investigation was the discovery that at a few stations better results would have been obtained with two readings a day than with continuous gage-height records not correctly used, as in the use of two readings a day the errors were largely compensating, whereas the incorrect method introduced errors of a cumulative nature. At other stations equipped with recording gages it was found that two readings a day would have been enough to give results sufficiently accurate for all practical purposes, although greater refinement was obtained by the use of the recording gage. These discoveries must not be interpreted as arguments against the use of automatic gages. They are mentioned to show the necessity of first determining whether the conditions require the use of an automatic gage, and later, if the gage is installed, of making sure that the accuracy of the method used in computing the discharge is comparable with the accuracy of the gage-height data.

The problem is how to determine whether the conditions are such that two readings a day from an ordinary staff or chain gage will give satisfactory results and what different conditions will warrant the

[1] Presented at the conference of engineers of the water-resources branch, United States Geological Survey, Washington, D. C., Dec. 8, 1914.

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installation of an automatic gage. Also, how to determine at the time of establishing the station the type of gage needed.

The conditions which require the use of automatic gages may be summarized as follows:

1. Regulation of the stream by power developments.
2. Operation of canals and ditches delivering water for irrigation.
3. Fluctuations due to variation in run-off under natural conditions (*a*) caused by rain and (*b*) caused by melting ice and snow.
4. Inaccessibility of gaging station or lack of reliable observer.
5. Continuous record needed for legal purposes.
6. Human fallibility of most gage observers.

The great increase in the number of water-power plants during the last 10 years has affected many streams. The operation of some of these plants gives nearly complete regulation of the stream at all stages; that of others affects only the low-water flow. An examination of the hydrograph of Quaboag River at West Brimfield, Mass. (fig. 25, *A*), which is illustrative of a type of hydrograph obtained under very complete power regulation, should convince one of the impossibility of making reliable estimates of discharge from gage readings obtained twice a day at this station. For streams of this class there can be no question regarding the necessity of using automatic gages, whatever the purpose for which the data are required. This stream has a large natural storage in ponds and lakes and would not be subject to severe fluctuation under natural conditions.

A partly regulated stream is illustrated by the hydrographs of Swift River at West Ware, Mass., shown in figure 25, *B*. This stream is also in the central part of Massachusetts and its natural conditions are similar to those of Quaboag River. From the hydrographs it may be seen that for a mean discharge below 100 second-feet the regulation is such as to change the natural conditions of flow entirely and would make gage heights taken twice a day of little value. For a mean discharge of 200 second-feet the power effect is slight, the peaks on the gage-height hydrograph being nearly submerged. Above 300 second-feet there appears to be no appreciable effect from power operation. For this particular stream the data obtained without the use of an automatic gage would probably be classed as "good" for about three months of the year, "fair" for about four months, and decidedly "poor" for the remaining five months. Any use of the data requiring a knowledge of the low-water flow would of course call for continuous gage-height records.

In order to insure the highest efficiency in the operation of an irrigation system, it is necessary to study the distribution of the water from the time of diversion from its natural course until it is applied to the soil. Continuous records of flow at various points on a canal are the only means of determining the amount of seepage losses.

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These losses, though apparently insignificant, may prove after investigation to be serious enough to make the lining of the canal a paying investment. Another feature of the operation of an irrigation system is the division of water, and it is generally true that a division satisfactory to all parties must be based on continuous automatic-gage records.

An example of violent fluctuation caused by rainfall is shown in figure 26, which is a gage-height hydrograph of the North Fork of Wailua River, on the island of Kauai, Territory of Hawaii. This hydrograph shows a difference in stage during one day which corresponds to 300 per cent of the mean discharge for the day. The

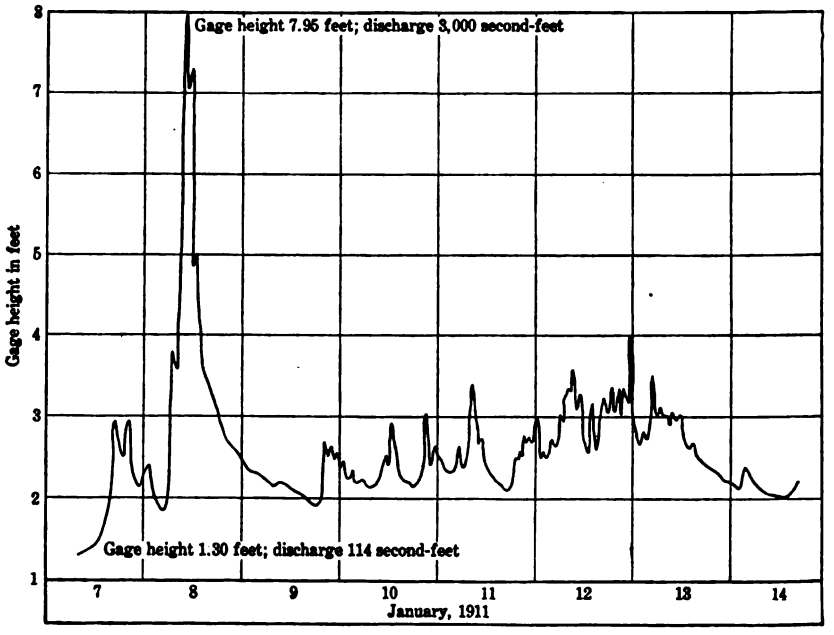

FIGURE 26.—Automatic-gage record, North Fork of Wailua River near Lihue, Kauai, Hawaii.

general appearance of the hydrograph should convince one at a glance that reading gage heights twice a day at this station would be of little value. Fluctuations due to rainfall are more uncertain than those due to other causes, for no one can successfully predict when they will be likely to occur. The necessity of using automatic gages on streams where accurate flood data are required is evident. The peak of the flood may be of only a few minutes' duration and therefore likely to be missed if observations are limited to two or even more than two readings a day taken during waking hours. A knowledge of the absolute maximum and its duration may be all important in connection with flood prevention.

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Streams fed by melting ice and snow are subject to large diurnal fluctuations which occur with considerable regularity. The gage-height hydrograph of Kings River near Sanger, Cal. (fig. 27), gives a good illustration of this type of fluctuation. This hydrograph shows that in May the difference in stage during the day averages about 30 per cent of the mean discharge for the day. For periods later in the season the flow of this type of stream is likely to be more uniform, so that it might be possible to obtain fair results during a part of the year from readings twice a day. Many streams in the mountains of California, Colorado, and other Western States are affected by this condition. As the waters of those streams are usually of value for

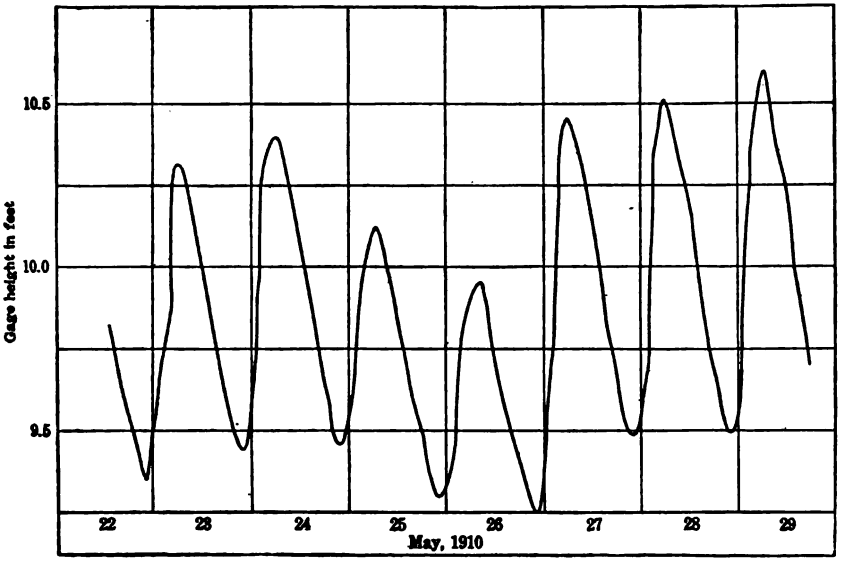

FIGURE 27.—Automatic-gage record, Kings River near Sanger, Cal.

irrigation and frequently conflicting interests present priority claims, it may be seen that the data should be based on continuous records.

Probably many stations have been established and are now being maintained at places where the strongest argument in favor of those particular sites was their convenience to the observers. An observer must be had, and if one could not be found near the desirable station site, then the station must be established at a site where an observer is available. The difficulties of rating the station and the effects of ice and log jams were subordinated to accessibility, for the gage reader was the first and principal consideration. However, the human equation of the observer need not have so great an influence at the present time, for at least two types of automatic gages now on the market can easily be installed so as to give a continuous gage-height record

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possible to the exact site decided upon for the station, and the data obtained by it should be referred to a permanent bench mark. If possible, two or more runs should be made, one at low stage and the others at intermediate stages. Discharge measurements should be obtained so that an approximate relation between change in gage height and change in discharge may be determined. The use of a portable gage for a preliminary study may possibly be the means of saving many dollars that would be required for an expensive gage installation. On the other hand, such a study may show the need for an automatic gage and decide the question by positive proof rather than by personal opinion. Figure 29 shows a gage-height hydrograph obtained by the use of a portable recording gage on Ausable River at Ausable Forks, N. Y. Owing to regulation by paper mills a short distance above the station the reading of gage heights twice

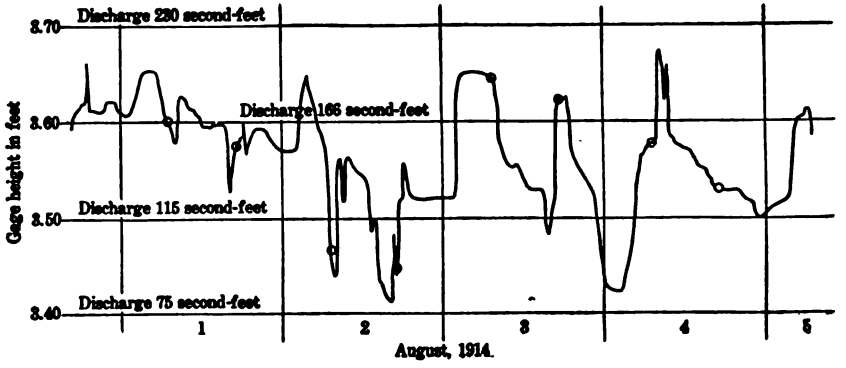

FIGURE 29.—Portable-gage record, Ausable River at Ausable Forks, N. Y.

a day was thought to be insufficient for the determination of discharge, and an automatic gage was considered necessary. In order to obtain positive proof of the need for an automatic gage, a portable gage was set up by the side of the chain gage and continuous records were obtained from July 10 to October 4. The data for August and September were computed by the method of reading gage heights at 7 a. m. and 5 p. m. and also on the basis of hourly discharge. For August the readings twice a day gave a monthly mean error of +3.5 per cent; for September, −0.5 per cent. Although some large errors occurred in the values for individual days, the monthly means were considered sufficiently accurate for present requirements, and the installation of an automatic gage at that station has been indefinitely postponed. The only expense item chargeable to the installation and maintenance of the portable gage consisted of 59 cents expressage.

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The hydrograph shown in figure 30 was obtained by the use of a portable gage on Winooski River at Montpelier, Vt. Several runs were made at different stages, and the data obtained showed conclusively that an automatic gage was necessary. Various makes of gages are adapted to these preliminary studies, the main requirements being compactness and simplicity of operation. This study by means of a portable gage may also be of assistance in determining the type of automatic gage to be installed if it is found that one is needed.

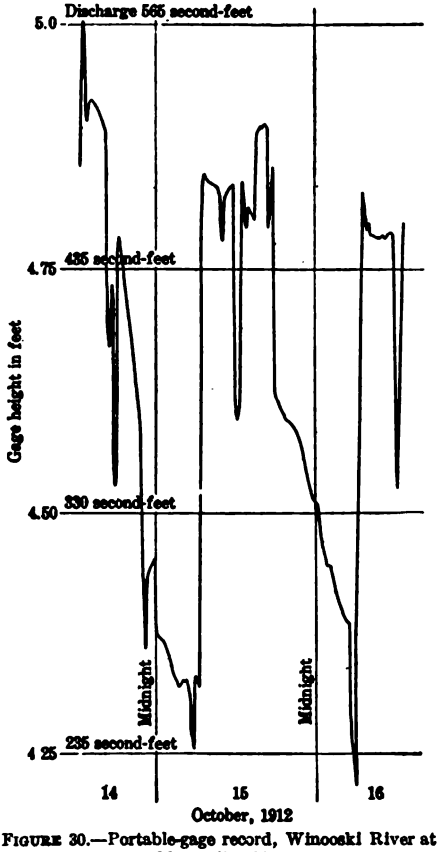

FIGURE 30.—Portable-gage record, Winooski River at Montpelier, Vt.

By a wise selection of gages and proper installation and by grouping instruments of the same type so that the needs of several can be cared for on the same inspection trip, in order to avoid the necessity of the engineer making special trips to remote points, the cost of maintaining automatic-gage stations should not greatly exceed the cost of properly maintaining the same stations equipped with staff or chain gages only. The necessity for the right kind of installation must be emphasized, however, especially in those parts of the country where the winters are severe.

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soil consisting of coarse brown flint gravel in a matrix of black clay loam. These areas may be designated as the Uvalde Plain. They are coextensive with the gravels mapped as the Uvalde formation. (See Pl. VIII.) The vegetation consists of scrubby chaparral and prickly pear.

Oakville Plain.—The Oakville Plain occupies the southeastern portion of McMullen County and is coextensive with the area marked as the outcrop of the Oakville sandstone on the geologic map (Pl. VIII). This plain is not peculiar to McMullen County, but is one of several parallel belts of country making up the Rio Grande Plain.

In form the Oakville Plain is a cuesta, which may be defined as a low ridge with a very gentle slope on one side and a steep slope or scarp on the other, the shape having been developed by erosion of a series of gently inclined alternating hard and soft strata. The southeastern part is sublevel to rolling; the northwestern part is dissected and therefore rugged and hilly.

The more level portions of this plain are characterized by residual dark-gray or dark-brown loam soils that carry a high percentage of organic matter. These soils in most places support a heavy growth of mesquite, chaparral, cactus, guajillo, and other native brush. Where the topography is more broken the soil is sparse, but the familiar, thickly set brush, collectively designated by the name chaparral, including black chaparral or "black brush," white chaparral or "white brush," cat's claw, guallacón (locally pronounced wy-can'), and guajillo, is everywhere present.

The dissected western margin of the plain is a scarp, which trends northeastward across the county, and the hills so conspicuous in the topography of the southeastern portion of McMullen County are part of this scarp. Among them may be mentioned Lomo Alto, near the Duval County line, Los Tiendos, and Chusas Hills. (See Pl. VIII.)

Frio Plain.—The Frio Plain adjoins the Oakville Plain on the northwest. It lies mostly south of Nueces River in McMullen County, though in the eastern part of the county it extends north of the river. It is coextensive with the area marked as the outcrop of the Frio clay on the geologic map (Pl. VIII).

The Frio Plain is a sublevel to rolling area, not greatly dissected or broken. Its soils are fertile residual dark-gray to dark-brown loams containing a high percentage of organic matter. A black clay-loam soil also occurs. The gray and brown loam soils support a thick growth of chaparral, but on the black clay loam chaparral is absent and open prairie prevails.

Wellborn Plain.—The Wellborn Plain lies northwest of the Frio Plain and parallel to it, forming a belt about 7 miles wide that extends diagonally across McMullen County from the southwest to the

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northeast corner. It is coextensive with the area marked as the outcrop of the Fayette sandstone on Plate VIII. The Wellborn and Frio plains together form a cuesta that has a gently sloping surface on the southeast side and a pronounced scarp on the northwest side.

The southeastern part of the Wellborn Plain is a rolling area, not very greatly dissected. The soils here are prevailingly dark-gray and dark-brown loams that carry large quantities of organic matter. The vegetation is characteristically chaparral, mesquite, and cactus.

The northwestern part of the plain is rough, broken country, constituting a range of hills that includes Opossum Hill, in the vicinity of Crowther, the hills in the vicinity of Tilden, the hills 7 miles southwest of Tilden, and the Busky Hills, about 14 miles southwest of Tilden. In the places protected from erosion the soils are dark loams, but in many localities there is practically no soil, the country rock being exposed at the surface. The chaparral, however, pervades the barren spots as well as the more fertile areas.

Yegua Prairie.—The Yegua Prairie, which is coextensive with the outcrop of the Yegua formation (Pl. VIII), borders the Wellborn Plain on the northwest and occupies the southeastern part of Lasalle County and much of the northwestern part of McMullen County. In some places it is gently rolling and in others almost flat. The prevalent soil is a fertile black clay loam containing a large amount of organic matter. This belt is mostly treeless, but is covered with grass and presents a pleasing contrast to the chaparral-covered plains so common in southwestern Texas. Owing to the lack of transportation facilities these lands are at present almost entirely devoted to ranching.

Cook Mountain Plain.—The Cook Mountain Plain lies northwest of the Yegua Prairie and occupies the northwestern half of Lasalle County. It is coextensive with the outcrop of the Cook Mountain formation. (See Pl. VIII.) Its surface is sublevel to rolling. The prevalent type of soil is a red or brownish-red fine sandy loam, underlain by a bright-red sandy clay subsoil of rather compact structure. The soil is well suited for the growing of garden truck and cotton. The native vegetation consists of a heavy growth of mesquite, chaparral, prickly pear, tasajillo, guajillo, cat's claw, etc., in places so thick that passage through it, except by cutting the way with an ax, is impossible. Another type of soil which occurs on this plain but which is much less widely distributed, is a black loam on a red clay subsoil. This soil is not so thickly set with the native brush as the sandy loam. The black-loam type of soil prevails in the immediate vicinity of Gardendale, north of the Nueces, and of Atlee, south of the Nueces.

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VALLEY LANDS.

The valleys of Nueces and Frio rivers cut the upland plains, erally at right angles, the trend of the upland plains usually l northeast and the course of the valleys northwest. However valley of the Nueces in McMullen County and that of the Frio i eastern part of McMullen County parallel the trend of the plains

The uplands as a whole have a gradual and more or less uni slope to the southeast, or in the direction of the Gulf. The profi the valleys shows in general a similar slope, but the grade is quite so steep. However, the valleys are 50 to 200 feet below the eral level of the uplands. They have been partly filled with vium deposited by the streams. The valley lands are separable three groups, differing in geologic age, in soil and vegetal condit and in their level with respect to the present stream channels.

Middle Pleistocene terrace.—What may be called the mi Pleistocene terrace stands at a level about 40 to 60 feet above present stream bed in the Nueces and Frio valleys, in Lasalle McMullen counties. This terrace occupies a comparatively s area, appearing at irregular intervals on both sides of the stre The characteristic feature is the heavy coat of gravel, consis largely of flint and forming the surface of the flat. The vegeta consists of chaparral, guajillo, cat's claw, prickly pear, etc.

Lowest Pleistocene terrace.—The lowest Pleistocene terrace is n more extensive than the terrace just described, constituting main portion of the valleys of the two streams in the counties u consideration. It lies at a level 20 to 40 feet below that of middle Pleistocene terrace. The lands of this terrace are ne level and have been subject to very little erosion. The preva type of soil is a grayish-brown loam, rather high in silt and in pl containing a large quantity of fine sand. The soil has a grayish sometimes yellow appearance on the surface but appears much da immediately below. An especially characteristic feature of t soils is the great number of Recent land shells scattered through t causing the land to be locally known as "shell land." Nearl the irrigation farms in the Nueces Valley in Lasalle County u these terrace soils for growing truck crops. A heavy growt mesquite and prickly pear occupies these lands in their native s

Overflow terrace or bottom.—The lowest terrace in these str valleys lies at a level 10 to 20 feet below that of the lowest Pleisto terrace, or about 10 to 15 feet above the present stream beds. terrace is subject to overflow during periods of flood. The surfa level to gently undulating, but in places it is cut by so-called "bayo representing abandoned channels of the streams or of tribut discharging into them. A common soil of this terrace is a gray

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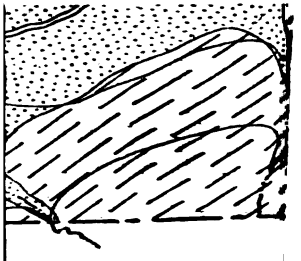

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brown to dark-brown silty clay loam underlain by a gray to slightly yellowish-gray or yellowish-brown silty clay loam, usually more compact than the soil. This soil supports a vigorous growth of mesquite, prickly pear, guajillo, tasajillo, several species of native grasses, and in places along the streams considerable live oak, pecan, hackberry, and sycamore. Another soil of this terrace is a dark-gray heavy plastic clay loam, varying somewhat in color according to the moisture content. On account of the high lime and humus content the soil when dry is loose and granular. When wet the color varies from dark drab to nearly black; when dry, from dark gray to slightly lighter shades. This soil in most places supports mesquite, prickly pear, and native grasses, but in the Nueces Valley from old Fort Ewell, in Lasalle County, to the Miles ranch, in McMullen County, it supports a heavy growth of sacahuiste grass, a tall, rank, coarse species. This portion of the Nueces Valley is locally known as the Sacahuiste Flats. The presence of the grass indicates the existence of salt in the soil.

GEOLOGIC OUTLINE.

General stratigraphy and structure.—The sediments exposed in Lasalle and McMullen counties comprise several formations belonging to two systems, the Tertiary and the Quaternary. (See Pl. VIII.) Deep wells also encounter formations belonging to the underlying Cretaceous system. The beds older than the Quaternary were originally almost horizontal but have been gradually elevated and tilted toward the Gulf. Since their elevation above the sea they have been subjected to erosion, those having the highest altitude and the longest period of exposure having suffered the most. The oldest and lowest formation exposed in these counties is therefore found along the west line of Lasalle County, at the greatest distance from the coast, and the youngest and uppermost formation, except the upland gravels and the valley deposits, is found in the southeast corner of McMullen County, at the least distance from the coast. The upland gravels and valley deposits were laid down after some tilting and erosion had taken place. In traveling from the southeast corner of McMullen County to the northwest corner of Lasalle County the geologist may inspect the entire series just as he could by descending a shaft sunk to the bottom of the series in the southeast corner of McMullen County. By thus determining the geologic section he can predict the sequence and character of the materials that would be encountered in sinking such a shaft or well. (See geologic section, Pl. VIII.)

An important feature in the geology of the area is a difference in the direction in which the formations dip on the opposite sides of a line extending from the northwest corner of Lasalle County to a point a short distance north of the southeast corner of McMullen

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County, as suggested by the underground contours in Plate IX. North of this line in Lasalle County the older Tertiary formations (Yegua and older—see table below) dip S. 28° E., whereas south of it they dip S. 71° E. On both sides the rate of dip is about 35 feet to the mile. In central McMullen County the Frio, Fayette, and Yegua formations (see table below) dip S. 48° E. at a rate of 48 feet to the mile; in northeastern McMullen County the same formations dip S. 51° E. at a rate of 68 feet to the mile; in southeastern McMullen County the Oakville sandstone (see table, p. 149) dips S. 79° E. at a rate of apparently only 14 feet to the mile.

Faults.—A normal fault having a vertical displacement of probably 40 feet or less, downthrow on the east side, and a trend of N. 30° E., is believed to exist in northwestern McMullen County. This fault is believed to enter McMullen County approximately 8 miles north of the southwest corner and to leave it approximately 10 miles west of the northeast corner. (See geologic map, Pl. VIII.) No exposures were found which show the fault, but its existence is inferred on the evidence of well sections and the quality of the water. Along this line and in most of McMullen County east of it nearly all the ground water, both deep and shallow, is very salty. As the chemical composition of the strata from which the water comes is not such as would account for this condition and as water derived from the same formation elsewhere is not salty, it would seem that faulting along the line indicated has afforded opportunity for the ascent of salt water from much lower levels.

A second fault cuts across the southeastern portion of McMullen County in a direction N. 40° E. (See Pl. VIII.) It is exposed at Los Picachos Hill, in Duval County; its trend toward the northeast in Live Oak County is inferred.

Geologic section.—The formations that are exposed or have been reached in drilling are shown in the following table and are described briefly under the heading "Water-bearing formations" (p. 150).

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The intake area is in eastern Maverick County and western and northern Zavalla County. (See Pl. IX.) East and south of this area the sand bed passes beneath the surface with a dip of about 35 feet to the mile. At Carrizo Springs these sands lie between depths of 230 and 530 feet, at Big Wells between 783 and 1,083 feet, at Cotulla between 1,480 and 1,780 feet, and at Fowlerton between 1,900 and 2,200 feet. The position of the base of this reservoir in Dimmit and Lasalle counties and northwestern McMullen County is indicated by means of contours on Plate IX.

Water-bearing sands are reported at a depth of 1,500 feet 1½ miles southeast of Woodward (well 100); 1,465 feet 1 mile east of Millett (well 96); 1,700 feet, more or less, at Gardendale; 1,600 feet 1 mile west of Cotulla (well 39); 1,560 feet, more or less, 1 mile northwest of Artesia (well 22); between 1,900 and 2,053 feet at Fowlerton (well 72); between 2,050 and 2,105 feet at Zella, 6½ miles north of Fowlerton (well 131); and between 2,986 and 3,002 feet 6¼ miles southeast of Tilden (well 128). All these sands belong to the Myrick formation.

Flowing wells are obtained by tapping the sands of the Myrick formation over an area in Dimmit County that has roughly the shape of a triangle whose vertex appears on the Nueces near the Zavalla County line and whose base coincides with the east line of Dimmit County where the Nueces crosses the line, being on this boundary approximately 10 miles wide. Flowing wells may be obtained by drilling to these sands in nearly all of Lasalle County east of the International & Great Northern Railroad and in the northwestern half of McMullen County. (See Pl. IX.) Most of the deeper and larger wells of Lasalle County, such as the wells at Woodward, Gardendale, and Fowlerton, draw their supplies from these sands.

In the eastern half of Dimmit County and in all of Lasalle County the water from the Myrick formation is suitable for domestic use, but it is bad for boilers because of its tendency to foam. It is not adapted for irrigation without taking special precautions to prevent damage from alkali. In the greater part of McMullen County (all the territory east of the fault line shown on Pl. IX) the water is too salty for use.

MOUNT SELMAN AND COOK MOUNTAIN FORMATIONS.

The Mount Selman and Cook Mountain formations consist largely of porous sand, charged with water, confined between the impervious clays at the base of the Mount Selman and the clays of the Yegua formation. The formations constitute an artesian reservoir which supplies wells in Lasalle and McMullen counties, though in McMullen County the water is so highly mineralized that it can not be used.

The intake area of these two formations is coextensive with their outcrop in the western half of Lasalle County. (See Pl. VIII.) In

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the southeastern half of Lasalle County and in McMullen County they are covered by younger beds. At Cotulla these sands extend downward from the surface to a depth of 670 feet; at Fowlerton they are found between depths of 250 and 1,140 feet; and 6¼ miles southeast of Tilden they are encountered between 1,250 and 2,150 feet.

Water-bearing sands of these formations occur at a depth of 182 feet 3 miles west of Woodward (well 97); between 160 and 164 feet, 195 and 201 feet, and 260 and 290 feet 1½ miles north of Gardendale; at 60, 110, 330, and 650 feet in the vicinity of Cotulla; at 80, 140, 185, 200, 400, and 500 feet in the vicinity of Artesia Wells; at 36, 125, 270, 400, and 670 feet in the vicinity of Artesia; between 116 and 146 feet and at 200, 348, and 450 feet in the vicinity of Encinal; between 342 and 373, 495 and 523, 1,050 and 1,142 feet, 1½ miles west-northwest of Fowlerton (well 80); between 1,040 and 1,080 and between 1,391 and 1,476 feet 4½ miles east of Tilden (well 127); and at 1,155 feet at Crowther.

Flowing wells are obtained by tapping these formations on low ground along the line of the International & Great Northern Railroad, in the vicinity of Artesia and Artesia Wells, and in the Nueces Valley at Cotulla. They are not obtained at Encinal and Gardendale, owing to the higher elevation of these places. East of the railroad in the eastern half of Lasalle County and in McMullen County flows are usually obtained wherever these sands are penetrated, but in these districts the water is generally so highly mineralized that it can not be used.

These sands are developed for water chiefly along the line of the International & Great Northern Railroad, where the depths do not usually exceed 600 feet, where the pressure is good, in places being sufficient to produce flows, and where the water is usually of such a quality that it can be used for drinking and cooking. In eastern Lasalle County and in McMullen County no wells are finished in these sands because of the very poor quality of the water.

In western Lasalle County water from these sands is commonly of the sulphate or chloride type and is, as a rule, suitable for domestic use, as at Encinal, Artesia, Artesia Wells, and Gardendale, and the deeper water at Cotulla, but it is poor for boiler use and irrigation. In eastern Lasalle County and in McMullen County water from these sands is usually a highly mineralized sodium chloride water unfit for domestic use, boilers, or irrigation.

YEGUA FORMATION.

The Yegua formation includes a number of sandy strata which will yield water. The formation supplies wells in the southeastern half of Lasalle County and in McMullen County, but the water in nearly all these wells is so salty that it is nearly valueless. Cattle will drink the water from a few wells tapping this reservoir.

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The outcrop area is in southeastern Lasalle County and in the northwestern half of McMullen County (see Pl. VIII), but the formation is covered by later beds in the southeastern half of McMullen County. At Fowlerton the Yegua formation extends from the surface to a depth of 250 feet; 6¼ miles east of Tilden it is found between depths of 625 and 1,140 feet. Water-bearing sands are found at various levels between these depths.

Water-bearing sands belonging to this formation occur also 1½ miles west-northwest of Fowlerton at a depth of 124 to 134 feet; at Zella, 6½ miles north of Fowlerton, between 110 and 115 feet; 5½ miles south-southwest of Fowlerton between 204 and 218 feet; 8 miles east-northeast of Tilden (well 125) between 563 and 620 feet; on the Byrne ranch, 8 miles east-northeast of Tilden (well 119), between 694 and 734 feet; and 1¼ miles south of Crowther (well 111) between 640 and 680 and between 820 and 840 feet.

The deeper sands on low ground usually produce flows. There are flowing wells supplied by these sands 4¾ miles southeast of Fowlerton, at Crowther, 5 miles southeast of Tilden (well 120), 8 miles east-northeast of Tilden (well 125), and on the Byrne ranch, 8 miles east of Tilden (well 119). All these wells are, however, without economic value because the quality of the water is such as to make it worthless for ordinary purposes.

FAYETTE SANDSTONE.

The name Fayette was first applied in Texas by Penrose in 1890 to deposits which are now subdivided into a number of formations. Dumble,[1] in 1892, separated the lower part of Penrose's Fayette and applied to it the name Yegua division, and in 1903[2] he made further discriminations. Kennedy,[3] in 1903, adopted the restricted definition for Fayette as proposed by Dumble. With the exception of Kennedy's 1893 report, in which the name Wellborn was used, all the reports dealing with this region since 1892 apply the name Fayette to the beds lying between the Yegua formation and the Frio clay.

Deussen[4] in 1914 made the following statements:

The fossiliferous Vicksburg limestone, as developed east of Louisiana, does not outcrop in Texas, nor has it been found in wells so far as known. The investigations of G. C. Matson[5] have shown that the Vicksburg limestone of Alabama grades into sandstone toward the west. Sandstone replaces the upper part of the Vicksburg in western Alabama, more of it in Mississippi, and still more in eastern Louisiana, and in

[1] Dumble, E. T., Report on the brown coal and lignite of Texas: Texas Geol. Survey, pp. 124, 148, 154, 1892.

[2] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, p. 922, 1903.

[3] Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, p. 21, 1903.

[4] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 69, 70, 1914.

[5] Unpublished notes.

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western Louisiana it replaces the whole Vicksburg, and even some beds of Jackson age are lithologically similar and apparently can not be separated.

As here interpreted, the Catahoula sandstone is a lithologic and stratigraphic unit which transgresses several biologic zones. Stated differently, it is conceived to be of different ages and to have been laid down at different epochs in the respective regions of its occurrence. In central Texas, in the region of the Brazos, it is largely of Jackson age. In eastern Texas it is largely of Vicksburg age. According to Matson the vertical transgression continues across Louisiana into Mississippi, where the formation lies above the Vicksburg limestone.[1]

The term Fayette is used in the present paper in the restricted sense in which it was applied by Dumble and Kennedy, and the deposits so called are the stratigraphic equivalents of the beds that were designated Wellborn by Kennedy in 1893. They are of Jackson age, occupying a part at least of the time interval of the fossiliferous marls and clays of the typical Jackson formation to the east.

The Fayette sandstone is a water-charged reservoir confined between the impervious clays of the Yegua at the base and the Frio clay at the top. This formation supplies wells in the southeastern half of McMullen County, but the water is in most places so highly mineralized that it can not be used.

The intake area is a northeastward-trending belt extending through the center of McMullen County. (See geologic map, Pl. VIII.) The formation dips underground beneath later formations in the southeastern half of this county. At Tilden it extends from the surface to a depth of 102 feet; at the Byrne ranch, 8 miles east of Tilden, it is encountered between depths of 25 and 410 feet.

Water-bearing beds of this formation occur at a depth of 100 feet 1 mile northeast of Crowther; between 280 and 300 feet 9½ miles east of Tilden; at 135 feet 12 miles east of Tilden; between 110 and 175 feet and between 330 and 360 feet 8 miles east-northeast of Tilden (well 119); and at about 350 feet 5 miles N. 20° E. from Lomo Alto.

Flows have been obtained from the deeper sands on low ground 9½ miles east of Tilden; 12 miles east of Tilden; and on the Byrne ranch, 8 miles east of Tilden (well 119).

Owing to the poor quality of the water from the deeper wells in this formation very little use is made of such wells, but some of the shallower wells are used for domestic purposes.

The water supplied by the sands of this formation is in most places (particularly in the district north of Frio River) so salty as to be unfit for drinking, for boilers, or for irrigation. Two shallow wells in the district south of Tilden (see analyses 115 and 116, p. 177) yield carbonate waters of moderate mineral content, good for domestic use, poor to fair for boilers, and poor or fair for irrigation.

[1] Studies made by the author since this report was written seem to indicate that the Catahoula sandstone as here described is not a stratigraphic unit but comprises two formations of similar lithologic character, the one at the base being of Jackson age, whereas the upper sandstone is of Oligocene age. The name Wellborn was applied by Kennedy to the lower of these two sandstones.

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FRIO CLAY.

The Frio clay contains some sand beds that would supply wells, but the water is probably too highly mineralized for use. So far as known there are no wells in McMullen County supplied from this source at present. The deposits are, like the Fayette sandstone, of Jackson age.

OAKVILLE SANDSTONE.

The Oakville sandstone crops out in the extreme southeastern part of McMullen County (see Pl. VIII), but as a source of water it is unimportant in this section. Where it is of considerable thickness, as near the corner of the county, it doubtless contains sufficient water to supply wells, but apparently no wells have been driven to it in McMullen County, and little is known concerning the quality of its water. So far as geologic data and some preliminary studies on the water supply of Live Oak and Duval counties indicate, the water from these sands is potable, though it is not well suited for boilers or for irrigation.

LATE PLEISTOCENE GRAVELS.

The gravels at the base of the lowest Pleistocene terrace on the streams in some places supply water permanently or intermittently to such shallow wells as penetrate them. Wells driven to them do not exceed 50 feet in depth, and their supplies are local and not dependable. In most places the water is very poor, owing to the high evaporation and consequent concentration of the salts, but in some places it is of fair quality.

At Shiner's ranch house, 10¾ miles S. 10° E. from Tilden, there is a well 22 feet deep supplied by these gravels with potable water, and a quarter of a mile east of Tilden there is a well 31 feet deep (well 113) supplied by these gravels with water that is potable but poor for boiler use and irrigation.

CHEMICAL CHARACTER OF THE WATER.

GENERAL CHARACTER.

The analyses in the table on pages 175–177 indicate that strongly mineralized alkali waters abound in Lasalle and McMullen counties. Almost all the waters tested exceed 500 parts per million in total mineral content, and nearly two-thirds of them exceed 2,000 parts. Sulphate and chloride waters predominate. Though only about one-quarter of the supplies are classed as sodium carbonate, more than half contain notable amounts of black alkali. Because of this generally excessive mineral content a large proportion of the waters are poor supplies, many being unfit for use. Drinkable waters have been found in many places, and a few are only moderately high in mineral

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that is bad for domestic use and unfit for boilers. The only water tested from the deeper part of the Myrick in this vicinity (analysis 22) is salty and unfit for use.

Wells at Cotulla, 100 to 300 feet deep, drawing chiefly from the Cook Mountain formation, yield sodium sulphate and sodium chloride waters that differ widely in quality. Some are fair for domestic use, but most are poor for irrigation and bad for use in boilers. Some wells, 1,800 to 2,500 feet deep, drawing from the Myrick formation yield less strongly mineralized waters, which are nevertheless poor for general use. A 2,424-foot well 1 mile west of Cotulla (analysis 40) yields, however, a soft water that is exceptionally low in mineral content and good for domestic use but poor for irrigation.

Shallow wells around Gardendale, drawing from the Cook Mountain formation, yield alkali waters ranging in mineral content from 900 to 2,600 parts per million. The supplies are generally fair or poor for domestic use, poor for irrigation, and poor for use in boilers. One water (analysis 95) from the Myrick, containing only 1,146 parts per million of total solids, is a fair domestic supply, though it is poor for irrigation.

At Fowlerton, on the Lasalle-McMullen county line, farther east than the places already mentioned, waters from the Cook Mountain formation are much more strongly mineralized. Those tested range in mineral content from 4,600 to 8,500 parts per million and are salty alkali waters unfit for use. The waters tested from the Mount Selman formation in the same neighborhood are somewhat better, ranging in mineral content from 1,200 to 6,000 parts per million. Most of them are, however, too strongly mineralized to be useful and must be classed as unfit for irrigation. The waters tested from deep wells entering the Myrick formation near Fowlerton are generally the lowest in mineral content. With two exceptions they contain about 2,000 parts per million of mineral matter and are not good supplies because of their carbonate character. One well tapping the Myrick southwest of Fowlerton (analyses 85 and 86) yields water unfit for use, as it contains more than 4,000 parts per million of solids. Another well recently drilled to the Myrick at Zella (analysis 131) yields distinctly better water that is good for domestic use, though poor for boiler use and for irrigation. These marked differences in the quality of water from wells supposed to draw from the same horizon in a relatively small area indicate either that water from upper strata finds access to the supplies or that the basal sands are not homogeneous.

The waters tested from deep wells near Tilden are distinctly bad. That from a well (analysis 126) entering the Cook Mountain formation (?) is salty and unfit for use. Two from wells tapping the Yegua formation (analyses 119 and 122) also are too strongly saline to be

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usable. A deep well entering the Myrick formation near Tilden yields similar water. Two shallow wells drawing from the Fayette sandstone south of Tilden afford waters of exceptionally low mineral content (analyses 115 and 116).

The composition of the few waters tested near Crowther indicates that deep wells drawing from the Yegua formation will yield salt waters unfit for use. The best water tested from this locality comes from a well about 100 feet deep (analysis 104) in the Fayette sandstone. The water is highly mineralized and of bad quality. The general indications are that deep wells in McMullen County will yield poorer waters than deep wells in Lasalle County. Though no analyses of water from the Myrick formation in eastern McMullen County are available, the water of one well entering that formation on the Kerr ranch, southeast of Tilden, is salty. It is probable that the Myrick contains salt water throughout eastern McMullen County.

QUALITY FOR DOMESTIC USE.

Waters that do not exceed 200 parts per million in total hardness and do not contain enough mineral matter to have a disagreeable taste are acceptable for drinking and cooking, though some of them might not answer all requirements of a good municipal supply. Hardness greater than 1,500 parts renders water undesirable for cooking, and water much softer than that consumes excessive quantities of soap in washing. Approximately 250 parts per million of chloride makes a water taste slightly salty. Somewhat less of the carbonate and somewhat more of the sulphate are detectable by taste. Yet though the lower a water is in mineral content the more acceptable it is as a source of domestic supply, the amount of dissolved substances that can be tolerated is much greater than is ordinarily believed. Alkaline carbonates apparently are most injurious, alkaline sulphates are least injurious, and alkaline chlorides occupy an intermediate position. Drinking water containing more than 300 parts per million of carbonate, 1,500 parts of chloride, or 2,000 parts of sulphate is unhealthful to most people. On these bases a sodium chloride water showing more than about 3,000 parts per million of mineral matter or a sulphate water showing more than 3,500 parts of mineral matter is reasonably classed as unfit for domestic use. The most obvious effect of drinking water too high in mineral content is usually diarrhea.

The total mineral content or dissolved solids of waters that were assayed has been estimated by the following formula:

$$\text{Dissolved solids} = 30 + 1.73CO_3 + 0.86HCO_3 + 1.48SO_4 + 1.62Cl.$$

The symbols represent the amounts in parts per million of the constituents determined by field assay, 30 being arbitrarily added for silica. In most of the results the figure for dissolved solids thus

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calculated does not equal the sum of the estimated scale-forming and foaming constituents (s+f). This disagreement is caused partly by error of assay, which is magnified by the methods of computation; it is caused mostly, however, by the necessary assumptions in the formulas, which, though they may cause some large numerical differences, do not destroy the comparative usefulness of the estimates. The total hardness as $CaCO_3$ of waters for which that determination was not made has been estimated thus: $H = 2.5Ca + 4.1Mg$. The waters have been classified as to mineral content by the following rating:

Rating for total solids.

Total solids (parts per million).		Class.
More than—	Not more than—	
.....	150	Low.
150	500	Moderate.
500	2,000	High.
2,000	.....	Very high.

The chemical character of the waters is suggested by expressing in symbols the predominant acid and basic radicles. The designation calcium (Ca) indicates that calcium and magnesium are predominant among the bases, and sodium (Na) that sodium and potassium are predominant, the application of either term being an assumption of the presence of the minor base; similarly the use of carbonate (CO_3), sulphate (SO_4), or chloride (Cl) shows which acid radicle is predominant. Combination of the two designations classifies the water by type; for example, the combined designation "sodium chloride" (Na–Cl) indicates that the water is a salt water; the designation Ca–SO_4 represents a gypsiferous water.

The rating under the heading "Quality for domestic use" is based entirely on the mineral content of the supplies and has no reference whatever to the possibility of pollution by sewage or other dangerous waste. As no bacteriologic examinations of the waters or sanitary inspections of the surroundings of the wells were made, no opinion as to the hygienic quality of the supplies can be given except in relation to their content of mineral matter. The waters in the table of analyses (pp. 175–177) classed as unfit for domestic use are too strongly mineralized to be drinkable; they exceed 1,500 parts per million in content of chlorine or 2,000 parts in content of sulphate, or are high in these constituents and also exceed reasonable limits in their contents of carbonate and bicarbonate. The waters classed as bad closely approach the limits of potability. Most of those classed as poor are drinkable but have a distinct taste of alkali or are excessively hard. Most of those classed as fair have little or no distinct taste but are too hard to be entirely acceptable.

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About one-third of the ground waters tested in these two counties may be considered good or fair for domestic use and slightly less than one-half are bad or unfit. About half the wells supplied chiefly from the Cook Mountain formation yield waters that may reasonably be considered good or fair. The proportion of good waters is somewhat smaller for the Myrick formation, though some of the best supplies are from that formation. In general, the waters of the Myrick are lower in sulphate and chloride than those of the Cook Mountain, but rather higher in carbonate and too high in total mineral content to be satisfactory.

QUALITY FOR IRRIGATION.

Water that contains much alkali is injurious to crops, because through evaporation the alkali gradually accumulates in the upper layers of the soil and eventually becomes so strongly concentrated that it is poisonous. The comparative value of the waters for irrigation has been estimated by applying the formulas developed by Stabler [1] for calculating the "alkali coefficient," which is defined by him as the depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops. Whether injury would result from the application of that quantity to any particular piece of land depends on several factors besides the alkali coefficient, namely, methods of irrigation, the crops grown, and the character of the soil and drainage conditions, and it should be clearly understood that the alkali coefficient takes no account of such factors. Waters relatively high in their content of alkali may be used without damage on a loose soil with free drainage, and some with still greater content of alkali may be applied to carefully selected land that is thoroughly underdrained by tiling or some similar means.

The alkali coefficients (k) computed by means of the following formulas are given in the tables of analyses:

$$k=\frac{2{,}040}{Cl} \text{ if } Na-0.65\ Cl \text{ is zero or negative.}$$

$$k=\frac{6{,}620}{Na+2.6Cl} \text{ if } Na-0.65\ Cl \text{ is positive but not more than } 0.48\ SO_4.$$

$$k=\frac{662}{Na-0.32Cl-0.43SO_4} \text{ if } Na-0.65Cl-0.48SO_4 \text{ is positive.}$$

The value of sodium (Na) for use in these formulas has been computed from the results of the field assays by means of the formula $Na=0.41HCO_3+0.83CO_3+0.71Cl+0.52SO_4-0.5H$, in which H represents the total hardness as $CaCO_3$.

[1] Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, p. 177, 1911.

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The value of the waters for irrigation has been expressed in words by use of the following classification, which is based on ordinary irrigation practice in the United States:

Classification of irrigation waters.

k.	Class.	Remarks.
More than 18	Good	Have been used successfully for many years without special care to prevent alkali accumulation.
18 to 6	Fair	Special care to prevent gradual alkali accumulation has generally been found necessary except on loose soils with free drainage.
5.9 to 1.2	Poor	Care in selection of soils has been found to be imperative and artificial drainage has frequently been found necessary.
Less than 1.2	Bad	Practically valueless for irrigation.

Though a few scattered waters in Lasalle and McMullen counties might be considered fair for irrigation, most of the waters contain too much alkali to make it advisable to irrigate with them, and many are unfit for that purpose. The salt waters that might perhaps be used would have to be applied with unusual and expensive provisions for drainage in order to prevent the accumulation of alkali, and the large quantities that would have to be applied frequently in order to prevent concentration of alkali by evaporation would doubtless render pumping out of the question.

Two-thirds of the waters tested are classed as poor, only four as fair, and none as good for irrigation. Nearly half exceed 2,500 parts per million in their estimated content of mineral matter, and one-quarter exceed 4,000 parts. In other words, though a few waters have been found that might be applied to land without causing undue accumulation of alkali, the majority could not be used for any length of time under ordinary conditions of irrigation. It should be understood that these statements refer only to the character of the waters themselves and not to the condition of the soils that are irrigable or the crops that might be planted.

Artesian waters carrying very great quantities of soluble matter are used for irrigation in certain oases of Sahara Desert,[1] where vegetables sensitive to alkali are successfully irrigated with water containing as much as 8,000 parts per million of soluble salts, half of which in some waters is sodium chloride. That concentration is equivalent to about 2,400 parts per million of chlorine. Twelve of the ground waters examined in Lasalle and McMullen counties contain more than that amount of chlorine, and several others contain at least half as much. Special attention may be called to the fact that thorough drainage and frequent irrigation with very large quantities of water are essential where water having a high content of salt is

[1] Means, T. H., The use of alkaline and saline waters for irrigation: U. S. Dept. Agr. Bur. Soils Circ. 10, July 1, 1903. See also Proceedings of first conference of engineers of the Reclamation Service: U. S. Geol. Survey Water-Supply Paper 93, p. 255, 1904.

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c.—If $0.0828\ Mg - 0.0336\ CO_3 - 0.0165\ HCO_3$ is positive the water is corrosive (C). If $0.0828\ Mg + 0.0503\ Ca - 0.0336\ CO_3 - 0.0165\ HCO_3$ is negative no corrosion will occur because of the mineral constituents of the water (NC). If $0.0828\ Mg - 0.0336\ CO_3 - 0.0165\ HCO_3$ is negative but $0.0828\ Mg + 0.0503\ Ca - 0.0336\ CO_3 - 0.0165\ HCO_3$ is positive corrosion may or may not occur (?).

The following similar formulas have been applied to the field assays:[1]

$s = 30 + H.$

$f = 2.7\ (Na + K).$

c.—If $0.033\ CO_3 + 0.016\ HCO_3$ equals or exceeds 0.02 H no corrosion is likely to occur (NC). If 0.004 H exceeds $0.033\ CO_3 + 0.016\ HCO_3$ corrosion is likely to occur (C). If $0.033\ CO_3 + 0.016\ HCO_3$ is less than 0.02 H but greater than 0.004 H corrosion may or may not occur (?).

In these formulas SiO_2, Ca, Mg, Na, K, CO_3, HCO_3, and H represent, respectively, the amounts in parts per million of silica, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, and total hardness as $CaCO_3$, as determined by analysis.

The value of waters in respect to their scale-forming ingredients may be expressed in words as follows:

Classification of waters in respect to scale.

Scaling constituents (parts per million).		Classification.	Remarks.
More than—	Not more than—		
.....	90	Good.....	Unlikely to cause excessive formation of scale.
90	200	Fair.....	May be used without much trouble if boiler is cleaned regularly, but could be improved by softening.
200	430	Poor.....	Use attended by formation of much scale and softening advisable.
430	680	Bad.....	Treatment before use imperative.
680	.....	Very bad..	Almost useless in raw state, and softening attended by formation of excessive foaming constituents.

The waters have been classified rather liberally in respect to their content of foaming ingredients. Waters containing more than 800 parts of alkali salts are likely to cause trouble by foaming, and, though supplies containing as much as 1,700 parts per million of foaming constituents have been used in boilers, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

Few of the waters in Lasalle and McMullen counties are bad for boiler use because of excessive content of scale-forming ingredients, and probably few would cause corrosion through deposition of mag-

[1] Dole, R. B., Rapid examination of water in geologic surveys of water resources: Econ. Geology, vol. 6, p. 340, 1911.

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drawn upon interfere seriously with one another and produce a radical lowering of the water level. Wells near the limits of the flowing-well area generally cease to flow when extensive developments are made; then subsequent pumping further depresses the water level. Moreover, the pressure is lowered by improperly cased wells that discharge artesian water into the upper sands.

At Fort Worth there has been a lowering of the water level of more than 100 feet in the last 30 years; at Alta Loma, in Galveston County, more than 30 feet in 18 years; in the vicinity of Carrizo Springs, Dimmit County, many wells that formerly overflowed are now nonflowing.

In Lasalle County every possible precaution should be taken to conserve the ground waters that are of suitable quality for irrigation. Every well should be adequately cased down to the lowest water-bearing sand, the higher sands with lower head being excluded to prevent the escape of the lower waters into the higher sands. Abandoned wells should be plugged at the bottom with cement to prevent escape of water from the lower to the upper sands and thus to protect the pressure and retard the depression of the water level.

From the community's standpoint it is reckless to permit each landowner to put down as many wells as he pleases, for numerous wells on a single farm usually involve waste of the artesian water. A larger acreage can be irrigated with a given number of wells and a larger total supply can be developed if the wells are spaced sufficiently far apart—say one on each half section of land—than if they are grouped with a well on each 10 acres. Close spacing of wells results in interference among them, with consequent rapid depression of the water table and the attendant disastrous results. This effect does not manifest itself where wells are so spaced that each one is beyond the cone of interference of the others, and this spacing can be best obtained in Lasalle County by putting wells no closer together than one on each half section.

When flowing wells are not in use the interests of the community require that they be shut off. It is as illogical to permit flowing wells to run continually and to expect them to maintain their flow as it would be to open the fire hydrants in a city and then expect the pressure to be maintained. The need is imperative for cooperative or legal action to protect the water supply for use in permanent irrigation and to restrain individuals from acts conflicting with the permanent interests of the community.

The analyses of the water obtained at various levels in the well 1½ miles west-northwest of Fowlerton (see analyses 75–83, pp. 176–177) indicate that the water in the upper beds is much poorer than that in the Myrick formation, 1,870 to 1,957 feet below the surface. This condition is believed to prevail generally in Lasalle County and the

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northwestern portion of McMullen County. The water from the Cook Mountain and Mount Selman formations is much poorer in quality than the water from the Myrick. In Dimmit County the Myrick supplies water poor for irrigation in most places, but the Escondido formation supplies water that is suitable for irrigation.

All wells should be properly cased in order to shut off the undesirable upper waters completely and thus to preserve the purity of the lower waters. Where many wells are driven through both sands in a small area, as in an irrigation district, the resulting commingling of the poorer and the better waters injures the better water. Fortunately the danger of contamination of a district as a whole is not so great under these conditions in these counties as where the better water lies above the poorer and is under less head.

Even though wells are cased the mistake is often made of perforating the casing opposite each water-bearing sand in the expectation that the total supply will be increased thereby. This is poor practice in the area under consideration, because it either affords an opportunity for the commingling of the water from different horizons or weakens the pressure of the water from the lower sands, thus allowing the water to escape into the upper sands instead of rising to the surface. The only safe practice in these counties is to carry the well to the base of the Myrick or Escondido formations, to obtain in the bottom of the well a considerable thickness of coarse sand, to case to the top of this sand, and to observe every precaution in having a tight joint where the casing is set.

WELL DATA AND WATER ANALYSES.

In the following tables are given a list of wells in Lasalle and McMullen counties and detailed information concerning these wells and analyses of the water from most of them. The wells are grouped first by counties and then within the counties alphabetically by the post offices near which they are located.

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Data of wells in Lasalle and McMullen counties, Tex.

No.	Location.	Owner.	Depth of well.	Diameter of well.	Depth to water-bearing sand.	Horizon of water-bearing stratum.	Height of water above (+) or below (−) surface.	Flow per minute.	Approximate elevation of mouth of well above sea level.	Year completed.
	Lasalle County.		*Feet.*	*Inches.*	*Feet.*		*Feet.*	*Gallons.*	*Feet.*	
1	Artesia, 400 yards south of	T. J. Alderman	160	5	142–160	Cook Mountain	Flow (1903) No flow (1913)	2 (1903)	439	1903
2	Artesia, 200 yards west of	J. W. McInnes	300±	6	270	do	0		443	1903(?)
3	Artesia, ½ mile south of	Pruitt Commission Co.			(?)		No flow.		440	
4	Artesia, 150 yards northeast of.	M. H. Baine	120	6	100–120	Cook Mountain	−20 (1913)		433	1888
5	Artesia, 1½ miles east of	George B. Wiltse	475	7⅝–6	400	do	−27 (1913)		449	
6	Artesia, 3 miles southwest of, on Las Reices Creek.	E. W. Alderman	200		180–200	do	−8 (1913)		440	1911
7	Artesia Wells, ½ mile south of.	J. M. Ramsey	250		230–250	do	Flow (1913)	5 (1913)	440	1908
8	Artesia Wells, 300 yards southwest of.	A. G. Salmon	165	6–5	90–165	do	−26 (1913)	a 15	447	1909
9	Artesia Wells, 900 feet southeast of depot.	C. C. Hurley	194	6–4	100	do	−15 (1913)	a 10	442	1913
10	Artesia Wells, ½ mile northwest of.	Lasalle Land & Fig Co.	330	6	85–200	do	−28 (1913)	a 60 (1913)		1903 ?)
11	Artesia Wells, ½ mile north of	E. Neil Johnston	200	6	80–185	do	−35 (1913)	a 75	454	1912
12	Artesia Wells, 1 mile southeast of.	R. L. Hendrickson	248		248±	do	Flows.	5 (1913)	450	1909(?)
13	Artesia Wells, 1½ miles south of.	R. C. Maxwell	170	6	170(?)	do	−20 (1913)		455	1909
14	Artesia Wells, 1½ miles south of.	John Robuck	193	6–5	140–160	do	−38 (1913)	a 8	440	1900
15	Artesia Wells, 1½ miles southeast of.	J. M. Ramsey	450		430	do	+⅛ (1913)	24 (1913)	445	1900
16	Artesia Wells, 3 miles east of.	do	300		250	do	Flow (1913)	8 (1913)	430	1905
17	Artesia Wells, 7 miles northwest of.	John Hicks	150	6	70–140	do	+35 (1906) −35 (1913)		475	1906
18	Artesia, 100 yards west of	J. W. McInnes	487	7	487(?)	Mount Selman and Cook Mountain.	+9 (1902) +2 (1913)	45 (1902)	439	1902
19	Artesia, 500 yards south of	T. J. Alderman	500	6	(?)	Mount Selman (?)	+2 (1913)		450	1904
20	Artesia Wells, 100 feet north of.	Asherton & Gulf Ry.	400±	6	400(?)	do	0		437	1909
21	Artesia Wells, 5 miles west of.	J. Lynn Jones	130	6	10 0–130	Mount Selman	−70 (1913)	a 16	525	1913
22	Artesia, 1 mile northwest of	C. H. Bever	1,560(?)	10–6	1,560(?)	Myrick	+2 (1913)	60 (1913)	450	
23	Atlee, 600 feet northwest of	T. A. Coleman		6	(?)			(a)	521	
24	Cotulla, Courthouse Square	Lasalle County	165	8–6	40–110	Cook Mountain	−30 (1913)		440	1908
25	Cotulla, 400 yards northwest of	J. T. Carr	100	6	90	do	−48		436	1906
26	Cotulla, ¾ mile northeast of	W. N. Guinn	105	6	35–80	do	−35		445	1908
27	Cotulla, 1 mile north of	L. W. Gaddis	127		100	do	−40 (1913)		435	
28	Cotulla, 4 miles northeast of	Roy Lewis	100±		100±	do	No flow.	15	485	

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29 b30	Cotulla, 12½ miles northeast of; ½ mile northwest of Bolton.	E. C. Hatton	290	$5\frac{8}{16}$–$4\frac{8}{16}$	264–290	do	−20		430	1912
31	Cotulla, 13 miles northeast of; 1½ miles north of Bolton.	L. S. Elwell	200	$5\frac{8}{16}$–$4\frac{8}{16}$		do	−30	a 40	400	1908
32	Cotulla, 1½ miles southwest of.	Joseph Cotulla	330		330	Mount Selman	+4 (1913)	5 (1913)	425	
33	Cotulla, 300 feet south of depot.	International & Great Northern Ry.	1,008±		1,008(?)	Myrick (upper part)	+6 (1890) +2 (1913)		432	1882(?)
34	do	do	1,008±		1,008(?)	do	+6 (1890) +2 (1913)		432	1882(?)
35	Cotulla, 8 miles northwest of, at old Armstrong ranch house.		767±		767±	do	Flow (1902)		471	
36	Cotulla, 8½ miles east of; 2½ miles northeast of Bolton.	O. S. Dewees	2,000	8	1,800±	Myrick	+25 (1913)	160	375	1913
37	Cotulla, about 10 miles east-northeast of, on Dewees ranch.	do	1,850		(?)	Myrick (?)				Old.
38	Cotulla, 12 miles northeast of.	do	1,800	8	1,775–1,800(?)	Myrick	+25 (1913)	60	435	1913
39	Cotulla, 1 mile west of	Joseph Cotulla, sr	2,424		1,200–1,965	Myrick and upper part of Escondido.	+22 (1913)		425	1913
40	do	do	2,424		1,600–2,424	Myrick to basal part of Escondido.	Flow (1913)	1,000±(1913)		
41	Encinal, 150 feet southwest of.	T. A. Coleman	350		350(?)	Cook Mountain		(a)	550	
42	Encinal, 300 feet northeast of.	International & Great Northern Ry.	800	13–8	350–450	do	−70 (1913)	a 83	550	1908
43	Encinal, 300 feet southwest of.	G. M. Berry	146	6	116–146	do		0 (1913)	550	1902
44	Encinal, 600 feet south of	J. W. McMullen	350	6	348	do	−70 (1913)		550	1906
45	Encinal, ¾ mile northeast of, on sec. 498.	G. A. Welhausen	300		300±	do	−60 (1913)		545	1905
46	Encinal, ¾ mile north of	do	375		375(?)	do	−50 (1913)		555	1908
47	Encinal, 1½ miles west of	do	300		300(?)	do	−50 (1913)		565	1900
48	Encinal, 3 miles west of	do	275		275	do	−45 (1913)		575	1908
49	Encinal, 3 miles northeast of	Atlas R. Munn	175		160	do	−38 (1913)		530	
50	Encinal, 3 miles northwest of, in sec. 694.	G. A. Welhausen	258		258(?)	do	−30 (1913)		565	1896
51	Encinal, 5 miles northwest of, in sec. 650.	do	275		275(?)	do	−50 (1913)		565	1907
52	Encinal, 7 miles northeast of	S. S. Charles	506	5	490–506	do	−40 (1913)		510	1907
53	Encinal, 7 miles northwest of.	Ted Watkins	284	6	120–252	do	−110 to −130	a 7	575	1906
54	Encinal, 20 miles east of	Callaghan Land & Pasture Co.	1,975		200–1,348	Cook Mountain and Mount Selman (?).	Flow (1913)	100 (1913)	325	1913
55	Fowlerton, 5½ miles southwest of.	A. L. Warner			204–218	Yegua			400	1913
56	Fowlerton, 5½ miles northwest of.	Tennessee Garden Well.	340		340(?)	Cook Mountain			355	
57	Fowlerton, 7½ miles southwest of, at Dull ranch house.	Gus Jones	300 or 400		400(?)	do	−5		354	
58	Fowlerton, 3 miles west of	Fowler Bros. Land Co.	310	6		do	Flow (1906) −6 (1913)	12 (1906) 0 (1913)	328	1906

a Nonflowing well; pumped.

b Same well as No. 29 after casing had been repaired.

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Data of wells in Lasalle and McMullen counties, Tex.—Continued.

No.	Location.	Owner.	Depth of well.	Diameter of well.	Depth to water-bearing sand.	Horizon of water-bearing stratum.	Height of water above (+) or below (−) surface.	Flow per minute.	Approximate elevation of mouth of well above sea level.	Year completed.
	Lasalle County—Continued.		*Feet.*	*Inches.*	*Feet.*		*Feet.*	*Gallons.*	*Feet.*	
59	Fowlerton, 5 miles west of	Fowler Bros. Land Co.	295	6		Cook Mountain		4 (1906) 0 (1913)	335	1906
60	Fowlerton, 2½ miles southwest of.	do	366	6		do		4 (1906) 0 (1913)	352	1906
61	Fowlerton, 3 miles northwest of.	do	300	6		do		4 (1906) 0 (1913)	345	1906
62	Fowlerton, 5 miles northwest of.	do	720	6		Mount Selman (?)	Flow (1906) No flow (1913)	30 (1906) 0 (1913)	335	1906
63	Fowlerton, 6½ miles west of	do	1,000	6–4	1,000(?)	do	+3 (1913)	200	330	1908
64	Fowlerton, 7½ miles northwest of.	do	1,400		770–990	do		160	338	
65	Fowlerton, 7½ miles northwest of, on east side of Frio River.	do	1,400	6	770–990	do		160	338	
66	Fowlerton, 6½ miles west of; 1 mile northeast of Dull ranch.	do	1,000		1,000(?)	do				
67	Fowlerton, 6½ miles west of	do	1,000		1,000(?)	do				
68	Fowlerton, 7½ miles northwest of.	Gus Jones	1,000	4	1,000(?)	do	+3±		340	
69	Fowlerton, 13 miles northwest of, 6 miles northeast of Bolton.	Mrs. Helen Irwin	797	6	797(?)	do	+30 (1913)	160 (1913)	375	1906
70	Fowlerton, ½ mile west of	Fowler Bros. Land Co.	1,857	8–4	1,390–1,857	Myrick	+70	600	336	1911
71	Fowlerton, ½ mile west of, Hotel well No. 3.	do			(?)	do				
72	do	do	2,056		1,900–2,053	do	+100 (1913)	500	336	1912
73	do	do	2,056		1,900–2,053	do				
74	do	do	2,056		1,900–2,053	do				
[a]75	Fowlerton, 1½ miles west-northwest of.	do	1,957		342–373	Cook Mountain	Flow (1913)	5 (1913)	336	1914
[b]76, 77	do	do	1,957		495–523	do	Flow (1913)	10± (1913)	336	1914
[c]78	do	do	1,957		1,050–1,142	Mount Selman	Flow (1913)	20± (1913)	336	1914
79	do	do	1,957		1,400–1,427	Myrick (upper part)	+65 (1914)	40± (1914)	336	1914
80	do	do	1,957		1,870–1,957	do	+81 (1914)	217 (1914)	336	1914
[d]81–83	do	do	1,957		1,870–1,957	do	+81 (1914)	217 (1914)	336	1914

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84	Fowlerton, 4½ miles northwest of.	....do	1,792		1,775–1,792	....do	Flow (1913)	175 (1913)	335	1912
85	Fowlerton, 3 miles southwest of.	D. C. Richardson, jr.	1,850	8	1,500–1,850	....do		450 (1913)	355	
86	....do	....do	1,850	8	1,500–1,850	....do		450 (1913)	355	
87	Gardendale, ½ mile east of	Fred R. Zeigler	300	6	300(?)	Cook Mountain	−125		575	1908
88	Gardendale, 1 mile east of	J. L. Tinsley	301	8–6	150–200	....do		[e] 100 (1913)	570	1910
89	Gardendale, 1 mile east of, in sec. 81.	Jake Goodman	300	8–6	150–250	....do	−175 (?)	[e] 40	570	1909
90	Gardendale, ¾ mile southeast of.	J. R. Burnett	200	7	153–157	....do			570	1913
91	....do	....do	200	7	[f] 195–200	....do	−135 (1913)		570	1913
92	Gardendale, 1 mile east of	T. W. Arnison	295	6½	247–295	....do	−120 (1913)		590	1908
93	Gardendale, 1 mile northeast of.	J. W. Cain	372	6	140–380	....do		[e] 40+		
94	Gardendale, 2± miles northeast of.	Fritz Schneebli	308	8–6	308	....do	−94	[e] 40	575	1908
95	Gardendale, public square	Gardendale colony	2,360	14–2	1,700±	Myrick	−40	[e] 40	582	1909
96	Millett, 1 mile east of	W. C. Atkinson	1,465(?)	4	1,465(?)	....do	Flows.		450	
97	Woodward, 3 miles west of	A. Y. Armstrong	182	6	182	Mount Selman	−50 (1913)		495	1898
98	Woodward, 3½ miles southwest of.	J. B. Ownby and Mrs. E. K. Payne.	760		760(?)	Myrick (upper part)	+37 (1913)		490	1893
99	Woodward, 3½ miles southwest of.	....do	760		760(?)	....do	+37 (1913)		490	1893
100	Woodward, 1½ miles southeast of.	Creamer & Ireland	1,720	8	1,250–1,500	Myrick (middle and basal parts).	+32	700	480	1910(?)
101	....do	....do	1,720	8	1,250–1,500	....do	+32	700	480	1910(?)
102	Woodward	Woodward Vichy Co.	1,587		1,587	Myrick	+25 (1905) + 8 (1913)	[g]	510	1905(?)
103	....do	....do	1,587		1,587	....do	+25 (1905) + 8 (1913)	[g]	510	1905(?)
	McMullen County.									
104	Crowther, 3 miles northeast of.	Boston-Texas Corporation.	100±		100(?)	Fayette	−60±		310	
105	Crowther, 1 mile southwest of.	....do	750±	12	750(?)	Yegua	Flows.		240	1902
106	Crowther, 2 miles southeast of.	....do	(?)		(?)	Yegua (?)				
107	Crowther, 2 miles south of	....do	(?)		(?)					
108	Crowther, near	....do		8	523	Yegua				
109	Crowther, 1 mile south of	....do	525		525	....do				
110	Crowther, 1½ miles south of	....do	1,340	6	640–1,300	Yegua and Cook Mountain	+30	100		1902
111	....do	....do	1,728	12–4	640–1,728	Yegua to Mount Selman	Flows.	400±	240	1902
112	Crowther, near	....do	900±		900±	Cook Mountain	Flows.	200		1902
113	Tilden, ½ mile east of	W. H. Martin	31	60	28	Pleistocene	−28	[e] 1		1898
114	Tilden, 10 miles east of	C. E. Byrne	58	6	30–58	Pleistocene (?)	−30		256	1907

[a] Fowler Bros. Land Co., well No. 7; "Well baled for one-half hour, when water became so low and muddy that drilling was resumed; sample not a true one—mixed with slush water." Nos. 75–83 represent analyses of water from the same well.
[b] True sample of water from sand at 495–523 feet.
[c] Not a fair sample of water from the sand at 1,050–1,142 feet.
[d] True sample of water from this level; Nos. 81–83 are assays of the same sample.
[e] Nonflowing well; pumped.
[f] A lower sand in the well from which No. 90 was collected.
[g] Flow 15 gallons in 1913; yield on pumping, 125 gallons.

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Data of wells in Lasalle and McMullen counties, Tex.—Continued.

No.	Location.	Owner.	Depth of well.	Diameter of well.	Depth to water-bearing sand.	Horizon of water-bearing stratum.	Height of water above (+) or below (−) surface.	Flow per minute.	Approximate elevation of mouth of well above sea level.	Year completed.
	McMullen County—Con.		*Feet.*	*Inches.*	*Feet.*		*Feet.*	*Gallons.*	*Feet.*	
115	Tilden, 7 miles south of	W. A. Lowe	54	48	35	Fayette	−26 (1913)	(a)	265	1910
116	Tilden, 9 miles southwest of	Hugh Fitzpatrick	34	60–48	30	do	−14 (1913)		235	1893
117	Tilden, 12 miles east of		(?)		280–300	do				
118	do	S. A. Hopkins (?)	195	4¼–3¾	65–135	do	+15 (1897) Flow (1913)	10–15 (1897)	225	1897
119	Tilden, 8 miles northeast of	C. R. Byrne	741		694–734	Yegua (upper part)	+4 (1913)	200–300	256	1908
120	Tilden, 5 miles southeast of	Two Rivers Ranch Co.	700±	2½–1¼	640±	do	Flow.		430	1905(?)
121	Tilden, 10 miles east of	Herman Borchers	900			Yegua (?) (upper part)	Flow (1907) No flow (1913)		355	1907(?)
122	Tilden, 7 miles southwest of	W. A. Lowe			588	Yegua			375	
123	Tilder, 12 miles northeast of, north of Frio River.	Jacob heirs	627	10	611–627	do	No flow.		245	
124	Tilden, 6 miles northeast of	Dilworth Bros	350	4¼		do	Flows.		325	1893(?)
125	Tilden, 8 miles northeast of, north bank of Frio River.	C. R. Byrne	945		563–935	Yegua and Cook Mountain	Flows.		225	
126	Tilden, public square	McMullen County	920±	5 1/16–3	(?)	Cook Mountain (?)	Flows.		255	1902(?)
127	Tilden, 4½ miles east of	Two Rivers Ranch Co.	2,305		1,040–2,175	Cook Mountain to Myrick	Flows.		252	
128	Tilden, 6½ miles southeast of	do	3,002		2,986–3,002	Myrick	Flows.		420	1910
129	Tilden, 4½ miles east of	do	2,800±		2,157–2,175(?)	Myrick (upper part)				
130	Tilden, 11 miles south of	John Fitzpatrick	72	48	72		−46			
131	Zella	Mr. Pumphries	2,105		2,050–2,105	Myrick			375	1914

a Nonflowing well; pumped.

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Analyses of ground waters of Lasalle and McMullen counties.

[Parts per million except as otherwise designated.]

No.	Date of analysis.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).[a]	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Total dissolved solids.[a]	Scale-forming constituents.[b]	Foaming constituents.[b]	Probability of corrosion.[c]	Quality for boiler use.	Quality for domestic use.	Alkali coefficient (inches).[b]	Quality for irrigation.	Mineral content.	Chemical character.
1	Mar. 3, 1913	.....	0.0	.....	....	500	66	106	362	388	126	1,400	160	1,400	N. C...	Poor..	Fair...	3.0	Poor..	High.....	Na-Cl.
2	June 1, 1913	.....	.0	.....	....	500	9	211	246	459	92	1,350	120	1,400	..do...	..do...	..do...	2.7	..do...	...do.....	Do.
3	Mar. 4, 1913	.....	.0	.....	....	540	31	158	431	367	78	1,450	110	1,500	..do...	..do...	..do...	2.8	..do...	...do.....	Na-SO_4.
4	June 28, 1913	.....	.0	.....	....	790	24	137	689	617	156	2,200	190	2,100	(?)	Bad...	..do...	2.2	..do...	Very high.	Do.
5	.....do.....	.....	.0	.....	....	540	19	163	415	396	76	1,450	110	1,500	N. C...	Poor..	..do...	2.8	..do...	High.....	Do.
6	.....do.....	.....	.0	.....	....	480	14	249	492	258	154	1,400	180	1,300	..do...	..do...	..do...	3.6	..do...	...do.....	Do.
7	.....do.....	.....	.0	.....	....	670	29	163	626	412	80	1,800	110	1,800	..do...	..do...	..do...	2.5	..do...	...do.....	Do.
8	.....do.....	.....	.0	.....	....	670	34	153	655	454	160	1,950	190	1,800	..do...	Bad...	..do...	2.7	..do...	...do.....	Do.
9	.....do.....	.....	.0	.....	....	650	19	166	600	474	162	1,850	190	1,800	..do...	Poor..	..do...	2.8	..do...	...do.....	Do.
10	Dec. 8, 1913	.....	.....	.....	....	590	.0	269	444	469	166	1,700	200	1,600	..do...	..do...	..do...	2.7	..do...	...do.....	Na-Cl.
11	Mar. 3, 1913	.....	.0	.....	....	610	.0	284	626	372	198	1,800	230	1,600	..do...	..do...	..do...	3.0	..do...	...do.....	Na-SO_4.
12	.....do.....	.....	.0	.....	....	660	.0	149	574	508	118	1,850	150	1,800	..do...	Bad...	..do...	2.6	..do...	...do.....	Do.
13	June 28, 1913	.....	.0	.....	....	1,050	.0	295	919	739	154	2,850	180	2,800	..do...	..do...	Bad...	1.6	..do...	Very high.	Do.
14	Mar. 3, 1913	.....	.0	.....	....	320	.0	294	313	160	150	1,000	180	860	..do...	Poor..	Fair...	4.9	..do...	High.....	Do.
15	June 28, 1913	.....	.0	.....	....	530	29	180	574	319	74	1,600	100	1,600	..do...	..do...	..do...	2.7	..do...	...do.....	Do.
16	.....do.....	.....	.0	.....	....	700	19	180	511	522	44	1,800	70	1,900	..do...	Bad...	..do...	2.1	..do...	...do.....	Na-Cl.
17	.....do.....	.....	.0	.....	....	320	.0	443	372	188	352	[d]1,250	380	860	..do...	..do...	Poor..	6.6	Fair...	...do.....	Na-SO_4.
18	.....do.....	.....	.0	.....	....	590	14	210	475	405	80	1,600	110	1,600	..do...	Poor..	Fair...	2.6	Poor...	...do.....	Do.
19	Jan. 16, 1913	.....	.0	.....	....	450	13	210	238	387	92	1,400	120	1,200	..do...	..do...	..do...	3.0	..do...	...do.....	Na-Cl.
20	.....do.....	.....	.7	20	12	530	122	248	398	306	[b]99	[d]1,388	110	1,400	..do...	..do...	..do...	2.5	..do...	...do.....	Na-SO_4.
21	June 28, 1913	.....	2.0	.....	....	610	.0	366	1,252	1,180	2,050	4,100	2,080	1,600	C.....	Unfit.	Bad...	1.7	..do...	Very high.	Ca-SO_4.
22	Mar. 3, 1913	.....	4.0	.....	....	1,500	66	861	431	1,264	70	3,550	100	4,000	N. C...	..do...	..do...	.7	Bad...	...do.....	Na-Cl.
23	Mar. 4, 1913	.....	3.0	.....	....	720	13	77	756	724	468	2,400	500	1,900	C.....	Poor..	Poor..	2.5	Poor...	...do.....	Na-SO_4.
24	Mar. 3, 1913	.....	.0	.....	....	1,600	.0	173	626	1,980	410	4,300	440	4,300	(?)	Unfit.	Unfit.	.9	Bad...	...do.....	Na-Cl.
25	Jan. 16, 1913	.....	.0	.....	....	1,400	.0	189	1,104	1,071	54	3,550	80	3,800	N. C...	..do...	Bad...	1.1	..do...	...do.....	Na-SO_4.
26	.....do.....	.....	.0	.....	....	850	.0	298	864	449	73	2,300	100	2,300	..do...	Bad...	..do...	2.0	Poor...	...do.....	Do.
27	Mar. 3, 1913	.....	.0	.....	....	330	.0	347	383	152	234	1,150	180	890	..do...	Poor..	Good.	5.7	..do...	High.....	Do.
28	Jan. 16, 1913	.....	7.0	.....	....	880	.0	212	362	979	185	2,350	210	2,400	(?)	Bad...	Bad...	1.6	..do...	Very high.	Na-Cl.
29	Mar. 4, 1913	.....	.0	.....	....	830	35	302	690	491	64	2,150	90	2,200	N. C...	..do...	Fair...	1.8	..do...	...do.....	Na-SO_4.
30	June 28, 1913	.....	.0	.....	....	660	43	347	552	299	34	1,700	60	1,800	..do...	..do...	..do...	2.0	..do...	High.....	Do.
32	Mar. 4, 1913	.....	.0	.....	....	1,050	110	176	574	834	42	2,550	70	2,800	..do...	..do...	Bad...	1.3	..do...	Very high.	Na-Cl.
33	.....	16	.03	24	10	([e])	1.0	776	882	752	[b]101	[d]3,657	120	3,300	..do...	Unfit.	..do...	1.1	Bad...	...do.....	Na-SO_4.
34	Jan. 16, 1913	.....	.4	24	12	1,636	4.0	281	788	1,846	[b]108	[d]4,846	120	4,400	..do...	..do...	Unfit.	.9	..do...	...do.....	Na-Cl.
35	Mar. 27, 1902	.....	.....	5.5	.5	953	.0	605	236	745	16	[d]2,291	50	2,600	..do...	Bad...	Fair...	1.1	..do...	...do.....	Do.
36	**Mar. 4, 1913**	.....	**.0**	.....	....	640	**62**	**729**	**173**	**304**	**26**	**1,500**	**60**	**1,700**	**..do...**	**..do...**	**..do...**	**1.4**	**Poor..**	**High.....**	**Na-CO_3.**

[a] Calculated unless otherwise indicated.
[b] Calculated.
[c] C., corrosive; N. C., noncorrosive; (?), corrosion uncertain or doubtful; values calculated.
[d] Determined.
[e] Sodium (Na), 1,046 parts; potassium (K), 191 parts.

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Analyses of ground waters of Lasalle and McMullen counties—Continued.

No.	Date of analysis.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).[a]	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Total dissolved solids.[a]	Scale-forming constituents.[b]	Foam in constituents.[b]	Probability of corrosion.[c]	Quality for boiler use.	Quality for domestic use.	Alkali coefficient (inches).[b]	Quality for irrigation.	Mineral content.	Chemical character.
37	.....	.....	.....	3.0	1.5	462	481	.....	83	89	[b] 14	1,150	40	1,200	N. C.	Poor	Poor	1.7	Poor	High	Na_2CO_3.
38	Mar. 4, 1913	.....	.0	.....	.....	1,550	44	999	626	1,126	34	3,700	60	4,300	do	Unfit	Bad	.7	Bad	Very high	Na-Cl.
39	June 28, 1913	.....	.9	.....	.....	530	82	771	132	123	30	1,250	60	1,400	do	Poor	Fair	1.6	Poor	High	Na_2CO_3.
40	do	.....	.0	.....	.....	250	58	278	125	68	42	660	70	680	do	do	Good	3.8	do	do	Do.
41	Mar. 4, 1913	.....	1.0	.....	.....	550	22	149	690	310	212	1,700	240	1,500	(?)	do	Poor	4.3	do	do	Na_2SO_4.
42	do	.....	1.0	.....	.....	470	26	185	756	167	282	1,600	310	1,300	(?)	do	do	7.3	Fair	do	Do.
43	June 28, 1913	.....	.0	.....	.....	1,100	5.0	205	1,723	793	930	4,050	960	3,000	C	Unfit	Bad	2.1	Poor	Very high	Do.
44	Mar. 4, 1913	.....	1.0	.....	.....	560	.0	180	626	404	250	1,750	280	1,500	(?)	Poor	Poor	4.1	do	High	Do.
45	June 28, 1913	.....	.0	.....	.....	980	.0	88	984	893	384	3,000	410	2,700	C	Bad	Bad	2.0	do	Very high	Do
46	do	.....	.0	.....	.....	600	.0	225	765	335	262	1,900	290	1,600	(?)	Poor	Poor	4.0	do	High	Do.
47	do	.....	2.4	.....	.....	280	.0	274	254	168	176	910	310	760	N. C.	do	Fair	5.7	do	do	Do.
48	do	.....	.....	.....	.....	440	.0	298	574	213	264	1,500	290	1,200	(?)	do	Poor	5.3	do	do	Do.
49	do	.....	1.8	.....	.....	760	10	321	919	299	130	2,150	160	2,100	N. C.	Bad	Fair	2.4	do	Very high	Do.
50	do	.....	.0	.....	.....	450	.0	308	626	160	222	1,500	250	1,200	do	Poor	do	5.0	do	High	Do.
51	do	.....	1.2	.....	.....	510	.0	333	689	196	238	1,650	270	1,400	do	do	Poor	4.4	do	do	Do.
52	do	.....	.0	.....	.....	1,450	38	327	1,060	1,060	54	3,650	80	3,900	do	Unfit	Bad	1.0	Bad	Very high	Na-Cl.
53	.....	.....	.0	.....	.....	230	.0	293	103	216	204	780	230	620	do	Poor	Fair	5.6	Poor	High	Do.
55	Dec. 8, 1913	.....	.....	.....	.....	12,900	.0	925	1,292	18,580	2,610	32,850	2,650	35,000	(?)	Unfit	Unfit	.1	Bad	Very high	Do.
56	.....	.....	.....	32	10	1,700	249	.....	1,298	1,450	[b] 121	4,750	140	4,600	N. C.	do	do	1.0	do	do	Do.
57	Jan. 16, 1913	.....	1.3	118	22	3,086	.0	172	1,394	3,896	[b] 385	[d] 8,590	420	8,400	(?)	do	do	.5	do	do	Do.
63	Mar. 4, 1913	.....	.0	.....	.....	1,700	88	1,188	328	1,386	26	3,950	60	4,600	N. C.	do	do	.6	do	do	Do.
64	.....	.....	.....	44	15	2,122	264	.....	1,404	2,040	[b] 172	5,870	180	5,700	do	do	do	.8	do	do	Do.
65	Mar. 4, 1913	.....	.0	.....	.....	1,900	52	1,679	383	1,376	28	4,350	60	5,100	do	do	do	.5	do	do	Do.
66	Jan. 16, 1913	.....	.0	.....	.....	1,550	13	1,714	256	1,030	25	3,550	60	4,200	do	do	do	.6	do	do	Na_2CO_3.
67	Mar. 4, 1913	.....	.0	.....	.....	1,500	92	1,269	328	1,066	26	3,500	60	4,100	do	do	Bad	.6	do	do	Do.
68	Jan. 16, 1913	.....	.0	.....	.....	1,750	47	1,305	246	1,519	28	4,050	60	4,800	do	do	Unfit	.5	do	do	Na-Cl.
69	Mar. 4, 1913	.....	.0	.....	.....	510	57	747	140	134	28	1,200	60	1,400	do	Poor	Fair	1.6	Poor	High	Na_2CO_3.
70	Jan. 16, 1913	.....	.2	12	4.0	1,339	40	1,196	256	1,162	[b] 46	3,636	75	3,600	do	Unfit	Bad	.7	Bad	Very high	Na-Cl.
71	.....	16	[e] 4.4	3.5	1.1	[d] 1,220	715	.....	228	871	[b] 13	[d] 3,063	20	3,300	do	do	Unfit	.8	do	do	Na_2CO_3.
72	Jan. 16, 1913	.....	.9	16	8.0	808	96	1,214	176	346	[b] 73	[d] 2,248	90	2,200	do	Bad	Bad	1.1	do	do	Do.
73	Mar. 4, 1913	.....	.0	.....	.....	940	106	1,175	222	379	30	2,150	60	2,500	do	do	do	.9	do	do	Do.
74	Mar. 14, 1913	.....	.....	5	3.0	980	62	1,412	199	482	[b] 25	[d] 2,420	50	2,600	do	do	do	.9	do	do	Do.
75	Jan. 8, 1913	.....	.....	.....	.....	2,650	.0	283	1,380	2,650	120	6,600	150	7,200	do	Unfit	Unfit	.5	do	do	Na-Cl.
76	do	.....	.....	.....	.....	1,800	24	386	1,214	1,450	46	4,550	80	5,000	do	do	Bad	.8	do	do	Do.
77	do	.....	.....	.....	.....	1,850	24	382	1,214	1,490	46	4,600	80	5,000	do	do	do	.8	do	do	Do.
78	do	.....	.8	.....	.....	2,500	24	775	756	2,545	100	6,000	130	6,700	do	do	Unfit	.5	do	do	Do.
79	Jan. 5, 1914	.....	.....	.....	.....	1,750	.0	1,520	362	1,351	80	4,050	110	4,700	do	do	Bad	.6	do	do	Do.
80	Jan. 17, 1914	.....	.0	.....	.....	990	65	1,250	286	396	10	2,300	40	2,700	do	Bad	do	.9	do	do	Na_2CO_3.
81	Mar. 14, 1914	.....	.....	5.0	3.0	874	65	1,264	206	395	[b] 25	[d] 2,188	50	2,400	do	do	do	1.0	do	do	Do.
82	do	.....	.0	.....	.....	1,100	53	1,295	430	420	9.0	2,580	40	2,900	do	do	do	.9	do	do	Do.

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83	.....do.....	.....	.....	4.0	3.0	895	63	1,286	202	422	[b] 22	[d] 2,145	50	2,400	..do...	..do...	..do...	1.0	..do...	...do.....	Do.
84	Mar. 4, 1913	.....	.0	.....	.....	1,000	.0	1,224	208	583	16	2,350	50	2,800	..do...	..do...	..do...	.9	..do...	...do.....	Do.
85	.....	.....	.....	3.0	2.0	2,079	1,316	.....	349	1,400	[b] 16	5,100	40	5,600	..do...	Unfit.	Unfit.	.4	..do...	...do.....	Na-Cl.
86	Mar. 4, 1913	.....	.0	.....	.....	1,750	101	1,188	362	1,422	28	4,050	70	4,700	..do...	..do...	..do...	.6	..do...	...do.....	Do.
87	Mar. 14, 1914	.....	6.0	.....	.....	250	.0	181	372	102	176	900	210	680	(?)	Poor..	Fair...	12	Fair...	High.....	Na-SO_4.
89	Dec. 8, 1913	.....	.....	.....	.....	400	.0	430	247	469	470	1,550	500	1,100	(?)	Bad...	Poor..	4.0	Poor...	...do.....	Na-Cl.
90	June 28, 1913	.....	.0	.....	.....	490	.0	313	1,147	405	1,040	2,650	1,070	1,400	N. C..	Unfit.	Bad...	4.3	..do...	Very high.	Ca-SO_4.
91	.....do.....	.....	1.0	.....	.....	680	.0	352	1,061	328	488	2,450	520	1,800	(?)	Bad...	Poor..	4.3	..do...	...do.....	Na-SO_4.
92	.....do.....	.....	1.4	.....	.....	460	14	396	427	205	162	1,350	190	1,200	N. C..	Poor..	Fair...	3.1	..do...	High.....	Do.
93	Mar. 3, 1913	.....	1.0	.....	.....	340	.0	410	238	188	176	1,050	220	920	..do...	..do...	..do...	3.7	..do...	...do.....	Na-CO_3.
94	Jan. 16, 1913	.....	2.0	.....	.....	430	.0	336	323	286	164	1,250	190	1,200	..do...	Bad...	Poor..	3.3	..do...	...do.....	Na-Cl.
95	.....do.....	.....	.5	14	4.0	396	56	656	110	118	[b] 51	[d] 1,146	80	1,100	..do...	..do...	Fair...	2.1	..do...	...do.....	Na-CO_3.
96	Mar. 4, 1913	.....	.0	.....	.....	490	40	630	154	184	28	1,150	60	1,300	..do...	Poor..	do...	1.8	..do...	...do.....	Do.
97	.....	79	[f] 1	499	1.6	([g])	.....	50	2,916	2,390	1,255	[d] 8,222	1,500	5,500	C.....	Unfit.	Unfit.	.7	Bad...	Very high.	Na-SO_4.
98	Mar. 3, 1913	.....	.0	.....	.....	1,050	118	747	276	740	46	[h] 2,500	80	2,800	N. C..	Bad...	Poor..	1.0	..do...	...do.....	Na-Cl.
99	.....do.....	.....	.0	.....	.....	1,050	.0	910	256	740	28	2,400	60	2,800	..do...	..do...	..do...	1.0	..do...	...do.....	Do.
100	Jan. 16, 1913	.....	.3	10	4.0	246	30	350	104	92	[b] 41	[d] 768	65	660	..do...	Poor..	Good..	3.8	Poor..	High.....	Na-CO_3.
101	Mar. 3, 1913	.....	.0	.....	.....	390	.0	670	108	100	24	930	50	1,100	..do...	..do...	..do...	2.0	..do...	...do.....	Do.
102	.....	14	([i])	3.0	6.0	[d] 350	15	618	107	104	47	[d] [j] 1,012	30	950	..do...	..do...	Poor..	2.4	..do...	...do.....	Do.
103	Jan. 16, 1913	.....	.0	.....	.....	650	28	452	136	535	23	1,550	50	1,800	..do...	Bad...	..do...	1.6	..do...	...do.....	Na-Cl.
104	.....do.....	.....	11	210	20	1,011	.0	148	1,060	1,132	[b] 607	[d] 3,600	680	2,700	C.....	Unfit.	Bad...	1.7	..do...	Very high.	Do.
105	.....do.....	.....	.0	.....	.....	4,250	10	474	1,726	4,[illegible]57	67	10,250	100	11,000	N. C..	..do...	Unfit.	.3	Bad...	...do.....	Do.
106	.....do.....	.....	.0	.....	.....	2,350	.0	363	313	2,938	66	5,550	100	6,400	..do...	..do...	..do...	.5	..do...	...do.....	Do.
107	.....do.....	.....	.0	.....	.....	4,450	.0	68	54	6,3[illegible]4	157	10,500	190	12,000	(?)	..do...	..do...	.3	..do...	...do.....	Do.
113	.....do.....	.....	.0	.....	.....	290	.0	334	202	347	384	1,200	410	810	(?)	Poor..	Poor..	5.6	Poor..	High.....	Do.
114	.....do.....	.....	.0	.....	.....	1,400	.0	601	1,312	8[illegible]6	260	3,050	290	3,800	N. C..	Unfit.	Bad...	1.2	..do...	Very high.	Na-SO_4.
115	June 28, 1913	.....	1.0	.....	.....	170	29	244	98	20	36	460	65	460	..do...	Poor..	Good..	5.5	..do...	Moderate..	Na-CO_3.
116	Dec. 8, 1913	.....	.....	.....	.....	95	.0	274	7.0	94	176	430	210	260	..do...	..do...	Fair...	11	Fair...	...do.....	Ca-CO_3.
117	Jan. 16, 1913	.....	.0	.....	.....	6,050	.0	904	25	8,262	390	14,250	420	16,000	..do...	Unfit.	Unfit.	.2	Bad...	Very high.	Na-Cl.
119	.....do.....	.....	.0	.....	.....	4,850	.0	473	26	6,660	188	11,250	220	13,000	..do...	..do...	..do...	.3	..do...	...do.....	Do.
122	Mar. 14, 1914	.....	.0	.....	.....	2,700	.0	1,232	.0	3,197	126	6,250	160	7,300	..do...	..do...	..do...	.4	..do...	...do.....	Do.
126	Jan. 16, 1913	.....	1.2	32	16	2,676	.0	622	552	3,458	[b] 146	[d] 7,200	150	7,200	..do...	..do...	..do...	.5	..do...	...do.....	Do.
129	.....do.....	.....	.0	.....	.....	3,200	51	383	1,448	3,[illegible]92	48	7,750	80	8,600	..do...	..do...	..do...	.4	..do...	...do.....	Do.
130	Mar. 14, 1914	.....	.0	.....	.....	1,300	.0	400	1,256	885	248	3,650	280	3,600	..do...	..do...	Bad...	1.3	Poor...	...do.....	Na-SO_4.
131	May 15, 1914	.....	.35	6.0	7.0	375	34	571	106	158	[b] 44	[d] 1,060	60	1,000	..do...	Poor..	Good.	2.3	..do...	High.....	Na-CO_3.

[a] Calculated unless otherwise indicated.
[b] Calculated.
[c] C., corrosive; N. C., noncorrosive; (?), corrosion uncertain or doubtful; values calculated.
[d] Determined.
[e] $Fe_2O_3+Al_2O_3$.
[f] Aluminum (Al), 9.0 parts.
[g] Sodium (Na), 2,056 parts; potassium (K), 5.3 parts.
[h] Nitrate (NO_3), 0.06 part; free carbon dioxide (CO_2), 44 parts; hydrogen sulphide (H_2S), none.
[i] Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$), 7.6 parts.
[j] Organic and volatile matter, 18 parts.

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UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

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WATER-SUPPLY PAPER 376

PROFILE SURVEYS
IN
CHELAN AND METHOW RIVER BASINS WASHINGTON

PREPARED UNDER THE DIRECTION OF

R. B. MARSHALL, CHIEF GEOGRAPHER

Prepared in cooperation with
THE STATE OF WASHINGTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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PROFILE SURVEYS IN CHELAN AND METHOW RIVER BASINS, WASHINGTON.

Prepared under the direction of R. B. MARSHALL, Chief Geographer.

INTRODUCTION.

In order to determine the location of undeveloped water powers on the rivers of the United States, the United States Geological Survey has from time to time made surveys and profiles of some of the streams adapted to the development of power by low or medium heads of 20 to 100 feet.

The surveys are made by means of plane table and stadia. Elevations are based on heights derived from primary or precise levels of the United States Geological Survey. The maps are made in the field and show not only the outlines of the river banks, the islands, the position of rapids, falls, shoals, and existing dams, and the crossings of all ferries and roads, but the contours of banks to an elevation high enough to indicate the possibility of using the stream. The elevations of the bench marks left are noted on the field sheets in their proper positions. All gaging stations are shown on the maps, and the elevation of the zero of the gage is given.

CHELAN RIVER BASIN.

GENERAL FEATURES.

Chelan River forms the outlet of Lake Chelan, in Chelan County, Wash. The river, which joins Columbia River at Chelan Falls, Wash., is only 4 miles long and in this distance has a fall of 380 feet. The lake and valley have been described by Willis[1] as follows:

Lake Chelan is a slender body of water 65 miles long,[2] whose southeastern end lies open to the sky between the grass-grown hills of the outer Columbia Valley, while its northwestern lies in shadow between precipitous mountains in the heart of the Cascade Range. There are sandy hollows near its outlet, but beneath the cliffs of its upper course the water is profoundly deep.

In brief technical phrase the lake basin is a canyon modified, deepened, and dammed by glaciation. The canyon is that of the Stehekin-Chelan River, which rises in latitude 48° 30′ in glaciers of the Cascade Range at altitudes of 5,000 to 8,000 feet. The headwaters descend very abruptly, 1,000 to 1,800 feet in the first mile below the

[1] Willis, Bailey, Contributions to the geology of Washington: Physiography and deformation of the Wenatchee-Chelan district, Cascade Range: U. S. Geol. Survey Prof. Paper 19, pp. 58, 81, 1903.

[2] The length is 48 miles as measured on the Stehekin, Methow, and Chelan topographic sheets, U. S. Geol. Survey.

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glaciers, and combine in a U-shaped valley of gentler grade, the fall being 2,500 feet in 23 miles. This section is cut in rock bottom. For 12 miles farther downstream the valley is floored with bowlders, coarse gravel, and sand, and the slope is but 20 feet to the mile, ending in the delta which the stream is building in Lake Chelan.

The gravel-filled section of the valley is no doubt deeply cut in the solid rock, since but a short distance beyond the front of the delta the lake is more than 500 feet deep. For a distance of 35 miles the depth varies from 1,000 to 1,400 feet, 1,419 feet being the maximum as yet sounded. As the water surface is but 1,079 feet above sea, the bottom of the lake is for a short stretch 300 feet below sea level. * * * Fifteen miles from its outlet the lake begins to shallow, and in its lower reach does not exceed 200 feet in depth.

The water is retained at its present level by a dam of sand and gravel, which in the section exposed by Chelan River is seen to consist of several successive members, i. e., soil, coarse stream gravel, till, very coarse gravel in pockets or channels, and cross-stratified sands. The base of the drift is not exposed. This drift dam fills the preglacial valley by which the Stehekin-Chelan River once reached the Columbia, and the present outlet turns from the drift into the gneiss and granite south of it, and has there cut a deep rock gorge.

According to the altitudes above sea of rock in place in the Columbia several miles below the junction, that of the lowest rock sill over which the waters of Lake Chelan can have escaped is about 700 feet.

Development of the fall on Chelan River between the lake and the mouth is contemplated by the Great Northern Railway Co.

The results of profile surveys in the Chelan River basin are given in Plates I–III (at end of volume).

GAGING STATIONS.

The Geological Survey has maintained in the basin of Chelan River the gaging stations indicated by the following list. The stations are arranged in downstream order, the position of tributaries being indicated by indention. A dash after the date indicates that the station was being maintained June 30, 1915. A period after the date indicates discontinuance.

Stehekin River (head of Chelan River) near Stehekin, Wash., 1910–
Chelan Lake at Lakeside, Wash., 1897–1899; 1905.
Chelan Lake at Chelan, Wash., 1910–
Chelan River at Chelan, Wash., 1903–
  Railroad Creek at Lucerne, Wash., 1910–1912.

METHOW RIVER BASIN.

GENERAL FEATURES.

Methow River rises on the eastern slope of the Cascade Mountains, in the northern part of Okanogan County, flows southeastward and unites with Columbia River near Pateros. It is about 60 miles long, and its drainage basin, which lies west of the Okanogan basin and east of the basin of Chelan Lake, comprises about 1,700 square miles. The most important tributaries of the Methow are Chewack Creek,

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which joins it near Winthrop, and Twisp River, which enters from the west at Twisp.

The country is rough and mountainous and lightly forested. The mean annual rainfall ranges from 70 or 80 inches on the summit of the Cascades to about 15 inches at the mouth of the river. Irrigation is not practiced except on the lands lying contiguous to the streams. The climatic conditions are favorable for intensive agriculture.

A hydroelectric plant on Methow River just above Pateros supplies power and light for Pateros, Bridgeport, and Brewster and power to ranchers for pumping water from Columbia River for irrigation. The pumping plants along the Columbia in this locality require a lift of 30 to 125 feet. The flume of the power plant carries about 600 second-feet of water.

The results of profile surveys in the Methow River basin are given in Plates IV–V (at end of volume).

GAGING STATIONS.

The Geological Survey has maintained in the basin of Methow River three gaging stations as follows:

Methow River at Winthrop, Wash., 1912.
Methow River at Pateros, Wash., 1903–
Twisp River near Twisp, Wash., 1912–1913.

The dash after the date indicates that the station was being maintained June 30, 1915. A period after the date indicates discontinuance.

PUBLICATIONS.

The following publications of the Geological Survey contain the results of investigations of stream flow at stations in Chelan and Methow River basins:

Chelan River basin:
Annual Reports: Nineteenth, Part IV; Twentieth, Part IV; Twenty-first, Part IV.
Water-Supply Papers: 16, 28, 38, 100, 135, 178, 292, 312, 332 A, 362 A,[1] 392.[1]
Methow River basin:
Water-Supply Papers: 100, 135, 178, 214, 252, 272, 292, 312, 332 A, 362 A,[1] 392.[1]

Water-supply papers and other publications of the United States Geological Survey containing data in regard to the water resources of the United States may be obtained or consulted as indicated below:

1. Copies may be obtained free of charge by applying to the Director of the Geological Survey, Washington, D. C. The edition printed for free distribution is, however, small and is soon exhausted.

2. Copies may be purchased at nominal cost from the Superintendent of Documents, Government Printing Office, Washington, D. C., who will on application furnish lists giving prices.

[1] In preparation.

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3. Sets of the reports may be consulted in the libraries of the cipal cities in the United States.

4. Complete sets are available for consultation in the local c of the water-resources branch of the Geological Survey, as follo

Albany, N. Y., Room 18, Federal Building.
Atlanta, Ga., Post Office Building.
St. Paul, Minn., Old Capitol Building.
Madison, Wis., Capitol Building.
Helena, Mont., Montana National Bank Building.
Denver, Colo., 302 Chamber of Commerce Building.
Salt Lake City, Utah, Federal Building.
Boise, Idaho, 615 Idaho Building.
Phœnix, Ariz., 417 Fleming Building.
Portland, Oreg., 416 Couch Building.
Tacoma, Wash., Federal Building.
San Francisco, Cal., 328 Customhouse.
Los Angeles, Cal., Federal Building.
Honolulu, Hawaii, Kapiolani Building.

A list of the Geological Survey's publications will be sent on ap cation to the Director of the United States Geological Surv Washington, D. C.

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WATER-SUPPLY PAPER 377

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IV–X. Reconnaissance plan and profile of John Day River from mouth to Middle Fork, Oreg. (7 sheets, A–G) .. At end of volume.

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where the rivers are artificially confined in their channels. Along the immediate banks of the streams the land is relatively higher than that nearer the hills. The channels of the lower sections of the rivers are comparatively deep and are favorable for navigation. The valleys are used more or less for agriculture.

The principal tributaries received by Spokane River between the lake and the Columbia are Latah or Hangman Creek, which enters the stream from the south near Spokane, Wash.; Little Spokane River, which comes in from the north about 12 miles below Spokane; and Chamokane Creek, which is tributary from the north and forms the eastern boundary of the Spokane Indian Reservation. Its drainage area comprises about 5,880 square miles. Nearly all of the upper portion is heavily forested and a large area is included in the Cœur d'Alene National Forest.

The topography of the country is rugged and broken. The valley's sides are very steep and many of the peaks rise to regions of perpetual snow.

The mean annual rainfall at Spokane is 17 inches; at St. Maries, 20 inches; and on the summit of the Bitterroot Mountains it is probably 50 inches or more. A large portion of the precipitation, particularly at the higher altitudes, is in the form of snow whose gradual melting helps to feed the streams during the summer season. Occasionally the snow banks are melted suddenly by chinook winds, and when these winds are accompanied by heavy rainfall the flood damage is sometimes great, although its severity is mitigated to a large extent by the natural storage in Cœur d'Alene Lake.

The lands bordering Spokane River are for the most part agricultural. Above Spokane the valley is comparatively wide and level and is underlain throughout with coarse gravel that affords ample ground-water storage from which a liberal supply for irrigation can be drawn. A gravity ditch system diverts water from the right bank of Spokane River at Post Falls. Below Spokane, where the river enters a comparatively deep canyon, the agricultural lands consist of narrow strips along the river banks and are irrigated for the most part by pumping from the river. The lands flanking the canyon of Spokane River are high and are used extensively for wheat raising. The chief products of the region, however, are from its mines.

The Spokane affords a large amount of power. At Post Falls, 8 miles below the outlet of Coeur d'Alene Lake, the Washington Water Power Co. has constructed a dam and power plant. The crest of this dam is at elevation 2,116.5 feet above sea level and is provided with a bear-trap dam 100 feet long, by means of which the water can be raised 10 feet above the crest proper. There are also eight Tainter gates, which, when opened, afford an additional spillway length of 159 feet. The company's overflow privileges do not allow

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Spokane River at Spokane, Wash., 1896–
  Spokane Valley Land & Water Co. canal near Post Falls, Wash., 1911–
Spokane River near Long Lake, Wash., 1912—
  Little North Fork of Cœur d'Alene River near Enaville, Idaho, 1911–12.
  St. Joe River at Avery, Idaho, 1911–
  St. Joe River near Calder, Idaho, 1911–12.
  St. Maries River at Lotus, Idaho, 1911–12.
  Latah [Hangman] Creek at Tekoa, Wash., 1904–05.
  Latah Creek near Tekoa, Wash., 1904–05.
    North Fork of Latah [Hangman] Creek at Tekoa, Wash., 1904–05.
  Little Spokane River near Spokane, Wash., 1903–1905; 1911–

JOHN DAY RIVER BASIN, OREGON.

GENERAL FEATURES.

John Day River drains the country to the northwest of the Blue Mountains. The river rises on the divide between Grant and Baker counties, Oreg., flows westward and then northward, and joins Columbia River about 28 miles above The Dalles. Its principal tributaries are the North, Middle, and South forks. Its total drainage area is 7,800 square miles.

The general elevation of its headwaters is about 6,000 feet above sea level; at Fossil the elevation is 1,500 feet. The headwater region of the stream is forested. Except wheat, which is grown on the rolling uplands by "dry farming," no agricultural products of consequence can be raised without irrigation, and as the areas which admit of easy irrigation are confined to the immediate valleys of the streams comparatively little has been done in this direction. Several projects have been suggested under which, by means of storage reservoirs and high-line canals, large areas of very productive table-lands would be developed. The storage facilities are ample for this purpose.

The mean annual rainfall varies from 24 inches on the headwaters to 10 inches at the mouth. The winters are cold, and the streams are frequently icebound throughout the greater part of the winter.

The results of profile surveys in John Day River basin are given in Plates IV to X (at end of volume).

GAGING STATIONS.

The Geological Survey has maintained in the basin of John Day River the gaging stations indicated by the following list. The stations are arranged in downstream order, the position of tributaries being indicated by indention. A dash after the date indicates that the station was being maintained June 30, 1915. A period after the date indicates discontinuance.

John Day River near Dayville, Oreg., 1908–1914.
John Day River at Clarno, Oreg., 1914–

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John Day River at McDonald, Oreg., 1904–
South Fork of John Day River at Dayville, Oreg., 1908–1914.
Dayville ditch at Dayville, Oreg., 1910–1914.
Rock Creek near Arlington, Oreg., 1905; 1911.

PUBLICATIONS.

The following publications of the Geological Survey contain the results of investigations of stream flow at the stations indicated in the preceding lists:

Spokane River basin:
Annual Reports: Eighteenth, Part IV; Nineteenth, Part IV; Twentieth, Part IV; Twenty-first, Part IV; Twenty-second, Part IV.
Water-Supply Papers: 11, 16, 28, 38, 39, 51, 66, 75, 85, 100, 135, 178, 214, 252, 272, 292, 312, 332-A, 362-A,[1] 392.[1]
John Day River basin:
Water-Supply Papers: 135, 178, 214, 252, 272, 292, 312, 332-C, 362-C, 394.[1]

Water-supply papers and other publications of the United States Geological Survey containing data in regard to the water resources of the United States may be obtained or consulted as indicated below.

1. Copies may be obtained free of charge by applying to the Director of the Geological Survey, Washington, D. C. The edition printed for free distribution is, however, small and is soon exhausted.

2. Copies may be purchased at nominal cost from the Superintendent of Documents, Government Printing Office, Washington, D. C., who will on application furnish lists giving prices.

3. Sets of the reports may be consulted in the libraries of the principal cities in the United States.

4. Complete sets are available for consultation in the local offices of the water-resources branch of the Geological Survey, as follows:

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Helena, Mont., Montana National Bank Building.
Denver, Colo., 302 Chamber of Commerce Building.
Salt Lake City, Utah, Federal Building.
Boise, Idaho, 615 Idaho Building.
Phoenix, Ariz., 417 Fleming Building.
Portland, Oreg., 416 Couch Building.
Tacoma, Wash., Federal Building.
San Francisco, Cal., 505 Customhouse.
Los Angeles, Cal., Federal Building.
Honolulu, Hawaii, Kapiolani Building.

A list of the Geological Survey's publications will be sent on application to the Director, United States Geological Survey, Washington, D. C.

[1] In preparation.

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V–VI. Plan and profile of White River in vicinity of Tygh Valley, Oreg. (two sheets, A and B) ..... At end of volume.

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PROFILE SURVEYS IN 1914 ON MIDDLE FORK OF WILLAMETTE RIVER AND WHITE RIVER, OREGON.

Prepared under the direction of R. B. MARSHALL, Chief Geographer.

INTRODUCTION.

In order to determine the location of undeveloped water powers on the rivers of the United States the United States Geological Survey has from time to time made surveys and profiles of some of the streams adapted to the development of power by low or medium heads of 20 to 100 feet.

The surveys are made by means of plane table and stadia. Elevations are based on heights derived from primary or precise levels of the United States Geological Survey. The maps are made in the field and show not only the outlines of the river banks, the islands, the positions of rapids, falls, shoals, and existing dams, and the crossings of all ferries and roads, but the contours of banks to an elevation high enough to indicate the possibility of using the stream. The elevations of the bench marks left are noted on the field sheets in their proper positions. All gaging stations are shown on the maps and the elevation of the zero of the gage is given.

WILLAMETTE RIVER BASIN.

GENERAL FEATURES.

Willamette River drains a trough-shaped area extending north and south between the Coast and Cascade ranges in Oregon. The area is roughly rectangular, and is about 140 miles in length and about 85 miles in width. Willamette River proper is formed by the junction of three main tributaries, which unite in the vicinity of Eugene; these are the Middle Fork (considered the continuation of the main stream), the Coast Fork, and McKenzie River. The river is navigable for ocean-going vessels from its mouth to Portland, and for ordinary river steamboats from Portland to Corvallis, except during a few months of each year. From Corvallis to Eugene the river is navigable for light-draft boats at medium stages of the water. The falls of Willamette River at Oregon City are passed by a series of five locks, which are at present in private ownership.

The other principal tributaries of Willamette River are Santiam, Molalla, and Clackamas rivers. From the Coast Range flow Long

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Tom, Marys, Luckiamute, Yamhill, and Tualatin rivers. The drainage areas of this river and its principal tributaries are given below.

Drainage areas in Willamette River basin.

	Square miles.		Square miles.
Willamette at mouth	11,150	McKenzie River	1,040
Willamette at Oregon City	10,200	Santiam River	1,890
Willamette at Salem	7,520	Yamhill River	763
Willamette at Albany	4,860	Clackamas River	927
Coast Fork of Willamette	705	Tualatin River	690
Middle Fork of Willamette	1,450		

From the summit of the mountain ranges the slopes are steep, but they merge gradually into a wide alluvial valley or gently rolling agricultural lands.

The entire drainage area may still be considered densely forested. The portions of the basin that contribute most of the flow of the streams lie almost entirely within national forests, and privately owned timber lands extend from the boundaries of the national forests to the main stream in the valley, except where lands have been cleared.

Although records of precipitation at the summit of the Coast Range are meager, it is likely that the total annual rainfall is as much as 150 inches. On the eastern slope of the Coast Range the annual precipitation decreases very rapidly to about 40 inches, but it gradually increases again until at the summit of the Cascade Range it is approximately 100 inches. From north to south the same general variation is observed, although the differences are not so striking. At the mouth of the river the precipitation is about 50 inches, in the vicinity of Corvallis about 40 inches, and at the summit of the Callapooya Mountains, which form the southern boundary of the drainage area, 55 or 60 inches. Except on the summits of the mountain ranges this precipitation is almost entirely rain, 95 per cent falling during nine months, from September to May. On the mountain ranges part of the precipitation is snow, and the country is subject during the spring and fall to warm chinook winds, accompanied by rather sudden melting of these snows, which frequently cause considerable damage from floods. During the growing season, when the precipitation rarely exceeds 2 inches, the valley is practically arid. Although irrigation has not long been practiced in the valley, it is likely that before many years a large part of the agricultural bottom lands will be placed under irrigation. Small ditches and pumping plants have been constructed, and the returns from irrigated agricultural lands show an increase of 50 to 500 per cent in production over the nonirrigated lands.

Lying almost wholly within a narrow strip adjacent to the main divide of the Cascades, where the soil and underlying rock is porous,

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leading to Hood River, where a small hydroelectric plant of 325 kilowatts is tied into the same circuit. A branch line extends to Dufur.

The results of a profile survey on White River in 1914 are presented in Plates V and VI at end of volume.

The Geological Survey has maintained a gaging station on White River near Tygh Valley since June 18, 1911. A station was also maintained on Tygh Creek at Tygh Valley from June 9 to September 30, 1911, and from March 8 to October 15, 1912.

PUBLICATIONS.

Information concerning stream flow at the stations on the Middle Fork of the Willamette and White rivers has been published by the Survey as follows:

Middle Fork of Willamette:
Water-Supply Papers 178, 214, 252, 272, 292, 312, 332C, 362C, and 394.[1]
White River:
Water-Supply Papers 312, 332C, 362C, 394.[1]

Water-supply papers and other publications of the United States Geological Survey containing data in regard to the water resources of the United States may be obtained or consulted as indicated below.

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Salt Lake City, Utah, Federal Building.
Boise, Idaho, 615 Idaho Building.
Portland, Oreg., 416 Couch Building.
Tacoma, Wash., Federal Building.
San Francisco, Cal., 328 Customhouse.
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[1] In preparation.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 379

PROFILE SURVEYS IN 1914

IN

UMPQUA RIVER BASIN, OREGON

PREPARED UNDER THE DIRECTION OF

R. B. MARSHALL, CHIEF GEOGRAPHER

Prepared in cooperation with
THE STATE OF OREGON
John H. Lewis, State Engineer

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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XII–XIII. Plan and profile of North Umpqua River from Boulder Creek to Lake Creek and of Lake Creek to Diamond Lake, Oreg. (two sheets, A and B) ..... At end of volume.

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PROFILE SURVEYS IN 1914 IN UMPQUA RIVER BASIN, OREGON.

Prepared under the direction of R. B. MARSHALL, Chief Geographer.

INTRODUCTION.

In order to determine the location of undeveloped water powers on the rivers of the United States the United States Geological Survey has from time to time made surveys and profiles of some of those adapted to the development of power by low or medium heads of 20 to 100 feet.

The surveys are made by means of plane table and stadia. Elevations are based on heights derived from primary or precise levels of the United States Geological Survey. The maps are made in the field and show not only the outlines of the river banks, the islands, the positions of rapids, falls, shoals, and existing dams, and the crossings of all ferries and roads, but the contours of banks to an elevation high enough to indicate the possibility of using the stream. The elevations of the bench marks left are noted on the field sheets in their proper positions. All gaging stations are shown on the maps and the elevation of the zero of the gage is given.

GENERAL FEATURES OF UMPQUA RIVER BASIN.

Umpqua River is formed by the junction of its North and South forks near the city of Roseburg, in Douglas County, Oreg. The North Umpqua rises in Diamond Lake, on the summit of the Cascade Mountains, at an elevation of 5,300 feet and flows westward. The South Umpqua is also formed by two forks—the northern rising in Old Bailey Mountain, about 4 miles south of Diamond Lake, and the southern on the northern slope of Abbot Butte—and flows westward and northward. From the junction of its principal forks, Umpqua River takes a tortuous but in general northerly course to Elkton, beyond which its course is more nearly west until it discharges into the Pacific Ocean at Winchester Bay, in the northwestern part of

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Douglas County. Its drainage area at Scottsburg, just above tidewater, comprises about 4,000 square miles. The North Umpqua drains 1,080 and the South Umpqua 1,990 square miles.

The important tributaries of the Umpqua are Smiths River, which drains the low mountainous area near the coast; Elk Creek, draining the divide between the Umpqua and Willamette basins; Cow Creek, which drains the divide between Rogue River and the Umpqua basin; and the North and South forks.

The country is rough and mountainous and the streams flow in comparative narrow valleys bordered by narrow stretches of agricultural land. The general elevation of the headwaters is 6,000 feet, but a few snow-capped peaks rise to heights of 8,000 to 10,000 feet. As the elevation at Roseburg is 485 feet above sea level, it is evident that the North Fork falls nearly 4,800 feet in the 75 miles from Diamond Lake to Roseburg by the river channel. The lower part of the Umpqua has comparatively little fall, as is shown by the tortuous winding of the stream.

The region is one of the most densely forested in the United States, and probably 80 per cent of the drainage area can be classed as heavily forested. About one-fourth of the forest area is included in the national forests; the rest is owned by corporations and individuals.

The mean annual rainfall at Roseburg is 30 inches; at Drain, near the divide between the Willamette and Umpqua basins, it is 48 inches. The mouth of the stream probably receives as much as 60 inches per annum; at the headwaters the precipitation is 100 inches or more. Except on the headwaters, all the precipitation is in the form of rain during the nine months of the year from September to May.

Little or no irrigation has been practiced in the Umpqua Valley, although a few small ditches take water from the smaller creeks tributary to the North and South forks. Owing to lack of markets the power plants now being operated are all small.

GAGING STATIONS.

The Survey has maintained in the basin of Umpqua River the gaging stations shown by the following list. The stations are arranged in downstream order, the main stem of the river being determined by measuring or estimating its drainage area—that is, the headwater stream draining the largest area is considered the continuation of the main stream, and all stations from source to mouth are presented first; stations on the tributaries, in regular order from source to mouth, follow. Relations of tributaries are indicated by indention. The dash following the date indicates that the station was being

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maintained June 30, 1915; a period after the date indicates discontinuance.

Umpqua River, North Fork of South Umpqua (head of Umpqua River), near Tiller, Oreg., 1910–11.
South Umpqua River near Brockway, Oreg., 1905–
Umpqua River near Elkton, Oreg., 1905–
Cow Creek at Riddle, Oreg., 1911–
North Umpqua River near Hoaglin, Oreg., 1910–
North Umpqua River near Oak Creek and Winchester, Oreg., 1905–
Mill Creek near Ash, Oreg., 1907–

PUBLICATIONS.

Information concerning stream flow at stations in the Umpqua River basin has been published by the Survey in Water-Supply Papers 177, 214, 252, 272, 292, 312, 332–C, 362–C, and 394.[1]

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